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The University of the State of New York
New York State Museum
JOHN M. CLARKE, *Director*

THE SUSQUEHANNA RIVER IN NEW YORK AND EVOLUTION OF WESTERN NEW YORK DRAINAGE

BY

HERMAN L. FAIRCHILD

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INTRODUCTION, HISTORICAL OUTLINE

The Susquehanna river is a very ancient stream with a very complex history. The story of its evolution in relation to land slope, continental movements and rock structure involves all the geologic history of New York since early Paleozoic time; while its present relation to the adjacent stream systems requires the description of the somewhat anomalous and puzzling drainage and physiography of all of central and western New York.

Four factors are chiefly concerned in the physiographic evolution of New York, namely: (1) climatic; (2) epeirogenic; (3) stratigraphic; and (4) glacial. The first of these factors is important, but is so indeterminate that it can not be seriously considered in this study. The second factor, the up-and-down movements of the continental surface, or land warping, has been active, but probably has not been a cause of diversion or change in the direction of stream flow, although it has probably influenced the stream gradients and rate of erosion. The most effective factor in the production of the present complex arrangement of the valleys of central and western New York has been the control exercised by the rock strata. To the varying resistance of the rocks to subaerial erosion, due to the variations in thickness, composition and structure in their vertical succession, must be attributed most of the striking features and the peculiar relationship of the valleys and stream directions.

The glacial factor produced radical changes in direction and volume of river flow and has partially obscured the preglacial topography. The glacial effects will be described in detail because they are the conspicuous features within the valleys, and the ones most available for educational work.

The lower or southern portion of the Susquehanna river, lying in Pennsylvania and in the Appalachian belt of deformed strata, was involved in the folding and lifting of the strata in Permian time, the "Appalachian Revolution." The rivers of that area were the subject of an admirable essay by W. M. Davis as long ago as 1889 (see number 5 of the attached bibliography). His analysis of the very difficult problem was so good that no extended paper on the genesis of the rivers of central Pennsylvania has been written since. This writing of Davis's may not be urged on the neophyte in earth science, but to the advanced student it is a most stimulating paper.

Above the west border of the Lackawanna-Wyoming coal basin the Susquehanna and its tributaries lie in relatively undeformed strata, but exhibit great diversion from the ancient, primitive flow, due to the factors already noted. The physiographic history of this upper section has not been written, and the present writing does not claim to exhaust the subject. Large elements in the drainage history, involving vast eons of time are as yet undiscoverable, and although more data may be found there will be elusive elements remaining in mystery. Some of the greater changes in the dramatic history which are fairly clear, or may be reasonably inferred, however, make a very interesting story.

The west branch of the Susquehanna, lying wholly in Pennsylvania, does not fall within the province of the New York survey. It was not greatly affected by glaciation, at least in the way of glacial obstruction, and has a history much more simple and uneventful than that of the north branch, (see the map, plate 1). This bulletin relates only to the north branch of the Susquehanna river, and particularly to the part above the coal region. Its upper waters and most of the larger tributaries are in New York, and it is thought that in late Tertiary time this drainage lay wholly in New York, with northward flow to the Ontario valley (plate 5). Several critical localities in the early life of the streams which were changed by the diverted and enlarging river lie in Pennsylvania, and our study can not be closely limited by state boundaries.

ERAS		PERIODS	CONDITIONS IN WESTERN NEW YORK
Cenozoic	Quaternary	Present	Continental erosion
		Pleistocene	Glaciation, with land depression and subsequent uplift
	Tertiary	Pliocene Miocene Oligocene Eocene	Stages of continental uplift and continuous erosion
Mesozoic		Cretaceous	Erosion with peneplanation
		Jurassic Triassic	Erosion, with peneplanation, followed by uplift
Paleozoic		Permian	Continental uplift; "Appalachian Revolution"
		Pennsylvanian	Area wholly land, with low elevation
		Mississipian	Only the southern border yet submerged
		Devonian	Slow rise of land, progressing from north to south; producing emergence
		Silurian Ordovician Cambrian	Oscillations of land; prevailing submergence in oceanic waters
Proterozoic		Several long periods	Conditions unknown
Archeozoic		Vast length of time	Conditions unknown

The above table, suggesting the probable physical conditions in central and western New York during the long periods of geologic time, and a brief foreword or outline of the complicated history will help the reader to follow and appreciate the story.

When central New York was permanently lifted out of the oceanic waters, in late Paleozoic time, the river had its birth. The flow was southward into the receding sea, which was yet lying over most of Pennsylvania. The great mountain-making revolution at the close of Paleozoic time apparently did not change the direction of flow in New York. The succeeding long Mesozoic era is supposed to have been, for this area, a time of subaerial erosion, and the rather uniform height of the higher hills has been interpreted as evidence of the Mesozoic peneplanes.[1] The Mesozoic stream history is unknown. Our oldest valleys are believed to date from Tertiary time, but perhaps were inherited from the Mesozoic stream courses (plate 4).

---

[1] Davis's original spelling was "peneplain." But in emphasis of the theoretic geometric surface rather than of rocks, we now use "peneplane"; however, when speaking of the deposit or the topographic feature, the term "plain" is used; hence "near-plain."

In early Tertiary time the Susquehanna appears to have flowed southward into Pennsylvania by the present Tunkhannock valley, as suggested in plate 4. With continental uplift in Tertiary time, producing valley trenching with the rock control, the river was diverted, by "stream capture," to westward flow through Binghamton and Owego and with the excavation of the great Ontario valley the river was diverted northward through the Seneca valley, becoming a main tributary of the Ontarian river, with ultimate outflow to the Mississippi Valley.

A slight lowering of world climate produced continental ice sheets, and the advancing Quebec (Labradorian) glacier blocked the northward flow of the Susquehanna and other streams and forced it southward again.. When the ice sheet overspread all of New York, all of the rivers were extinguished. With the waning of the glacier the river was recreated, by headward growth, following the receding south front of the ice sheet. But the southward channel, past Towanda, had been so deepened and the former northward channel, past Elmira, had become so filled with drift that the river has retained its southward course.

The enormous volume of the glacial river helps to explain the high-level and widespread gravel plains in the main and tributary valleys. Two other factors are concerned with the valley filling: (1) the barriers of drift left by the ice sheet, and (2) the lower altitude of the land when the glacier melted away. The quickened flow of the streams produced by the postglacial land uplift (figures 1 and 2) along with the removal of the drift dams has resulted in erosion of the plains and in valley fillings, producing the present valley topography.[1]

The history of the Susquehanna is too involved and complicated to be told as a continuous narrative, and the reader will find some repetition and overlapping in the following chapters. The earlier chapters, describing the evolution of the drainage, are necessarily somewhat technical; but the second part of the story, the Pleistocene or glacial history, will be found easier reading, and holding more of local interest.

In the prosecution of this study the writer has been placed under pleasant obligation to many friends; for automobile transportation to F. R. Pierce, Susquehanna, Pa.; I. P. Shepard, Waverly; Edwin Smith, Sherburne; Thur Smith, Newark Valley; and Paul LeHardy,

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[1] The glacial history of the river in Pennsylvania will be published by the Pennsylvania Geological Survey.

David Z. Morris, J. Foster Warner of Rochester. For critical reading of the manuscript and helpful suggestions thanks are due George H. Chadwick and Chris A. Hartnagel. Data relating to the depth of drift in the valleys have been supplied by the following professional drillers: Charles A. Daggett, Russell Shear and Peter Vanderhoff of Elmira; F. O. McIntyre, Owego; and Chester Thomas, Milan, Pa.

The map (plate 1) covers a wide area in order to show the indifferent relation of the Susquehanna to the other neighboring drainage systems. Some of the inconsistencies of the present drainage may be noted.

The upper stretch of the North Branch Susquehanna and its higher tributaries, and also the upper waters of the Delaware, have southward or southwestward flow, which is thought to be direct inheritance from the earliest drainage. The trunk stream flows southwestward to Harpursville (plate 17), south-by-east to Lanesboro (plate 16), northwest to Binghamton, west-by-south to Waverly (plates 11, 15), and then southeast, with meanders, to Pittston, Pa. This varied direction suggests radical changes from the original direction of flow.

The tributary Chemung, from the northwest, receives the Tioga from the south. The Finger lakes all drain northward, but their combined outflow passes east to the Onondaga valley before it enters Lake Ontario by the Oswego river.

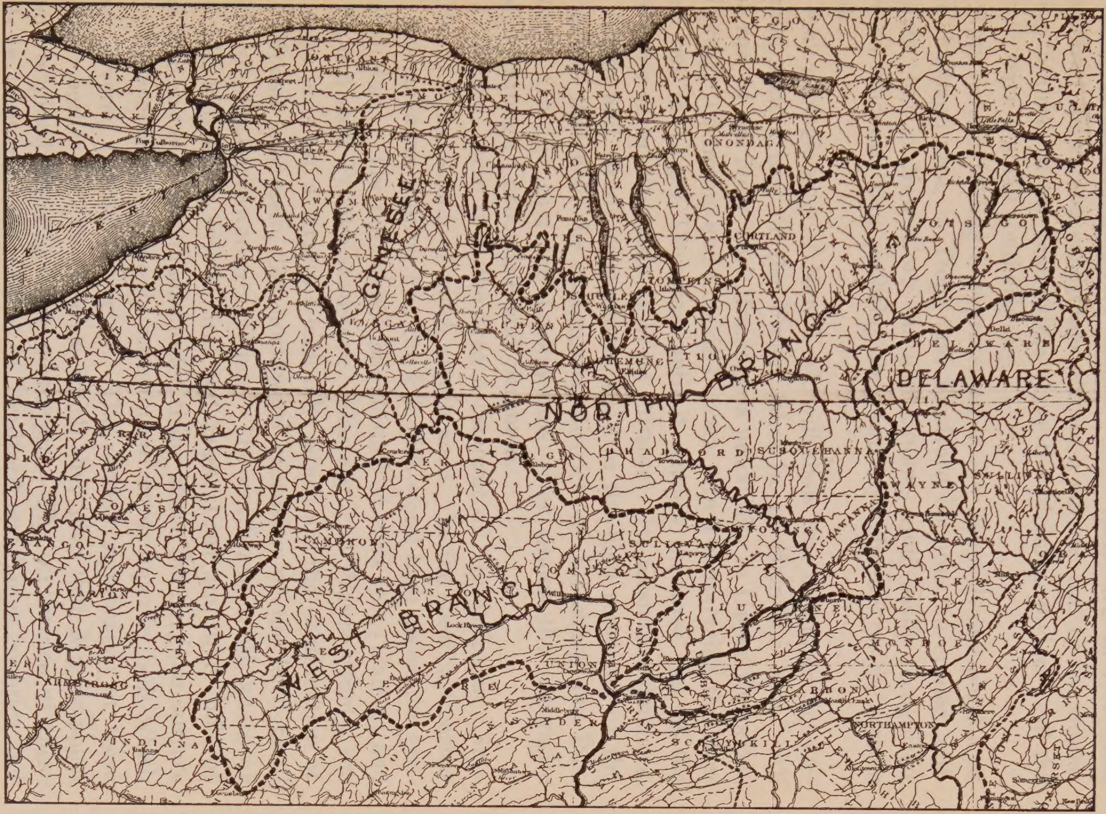
The West Branch Susquehanna gathers all its branches in a consistent dendritic manner for eastward flow to beyond Williamsport, where it turns south.

The headwaters of the Allegheny river flow northward into New York and then turn into southward flow, which is radical diversion from its preglacial flow (plate 5).

The Genesee river exhibits the most radical opposition to the primitive direction of drainage. Rising in Pennsylvania it flows north entirely across New York. It should be noted that the source of the Genesee river marks a locality of divergent flow. Streams head here for four distinct river systems: Genesee, Allegheny, and both the north and west branches of the Susquehanna. M. R. Campbell makes the center of his dome of the Harrisburg peneplane only about 30 miles west of the center of divergent drainage (map in 13).

It must be understood that the stream courses as they lie on the map are not sufficient basis for reading the drainage history, which requires for its full translation more geologic science than we possess today.

Plate I



Drainage Areas of the Susquehanna River

STRATIGRAPHY OF WESTERN NEW YORK

The stratigraphic geology of the Susquehanna drainage area in New York is comparatively simple. The rocks are all Devonian, unaltered shales and sandstones, except a narrow belt of the underlying Silurian at the headwaters along the Mohawk divide. All the strata have a small southerly dip.

Appalachian folding is represented in the Pennsylvania portion of the drainage area, in Tioga and Bradford counties, in eroded anticlines; but in New York the undulations, while easily recognized, are so moderate that probably they had no influence on the stream flow.

Any geologic map of New York will show that the upper Susquehanna waters east of the Finger lakes lie in Hamilton beds. All the rest of the New York drainage is practically in Upper Devonian, (Portage, Chemung and Catskill) strata. In Pennsylvania the river also lies in Upper Devonian until it reaches the west rim of the northern anthracite basin at West Pittston. Its western tributaries, in Tioga and Bradford counties, head in the high remnants of the synclines that hold the coal-mining districts of Blossburg and Barclay. On the east the Lackawanna river drains the anthracite valley through Carbondale and Scranton.

However, there is in the area a remnant of Mississippian (Subcarboniferous) strata of much significance. In the southeast corner of Susquehanna county, Pa., the Elk hills stand high above the general surface. The north knob has altitude of 2684 feet (plate 9) and is capped with Pocono sandstone. Eastward, in Wayne county, the Pocono beds cap a series of high hills which are the continuation of the Moosic mountain, the northward extension of the hard basal rocks of the Lackawanna syncline. The north and south knobs of the Elk hills along with Ararat and Sugar Loaf and other hills of the Moosic range are monadnocks, rising above the irregular surface of the peneplane, being only remnants of hard, superior beds which once covered the whole region. The present significance of these Pocono outliers is the evidence which they give that Mississippian strata originally extended far northward. The occurrence of these beds in remnants of synclines in Bradford and Tioga counties and in northwestern Pennsylvania, also in southwestern New York, indicates that Pocono sandrock once covered all of northern Pennsylvania and some unknown extent of southern New York.

The Elk hills give us the minimum of land erosion in the region. Plate 9 and figure 3 show the relief. The North Knob is recorded as 2684 feet above tide. The higher points of the region, in Catskill sandstone, suggest a peneplane at about 2100 feet, which implies a general erosion of nearly 600 feet since the Appalachian uplift. The Tunkhannock valley on the line of the profile (figure 3) and less than 6 miles west of the North Knob, has altitude of only 900 feet. At South Gibson, 4 miles northwest of the knob the valley bottom is 1000 feet. This gives a depth of stream erosion beneath the old peneplane of 1100 feet. This Tunkhannock valley was the channel of the Susquehanna river at the beginning of Tertiary time, as will be shown later in this bulletin.

The highland in New York which carries the Susquehanna drainage, now 2000 to 2500 feet above ocean, was sea bottom during Devonian time. The long and varied history previous to the Devonian does not concern the present story, except as to character of the rocks, which will be noted later. Some conception of the ups and downs of the continental surface may be had by study of Schuchert's maps of the ancient geography (21).

It appears that a belt along the south border of western New York was still submerged in Mississippian time, but that in Pennsylvanian (Coal measures) time all of the State was above the sea. All of the drainage of the New York area during Paleozoic time appears to have been southward, from the uplifted old land of Canada, across New York into the receding interior (epicontinental) sea. The present stream lines between the Hudson valley on the east and the Finger lakes area on the west are doubtless an inheritance from that ancient southward drainage.

Since that primitive stream flow was established, across New York from Canada, it has been affected by at least two periods of great continental uplift, and one epoch of overwhelming continental glaciation. The first great uplift was the Appalachian Revolution, in Permian time, closing the immensely long Paleozoic Era. The thick sediments in Pennsylvania were mashed and folded into a huge mountain system stretching from New York to Alabama. In New York this great disturbance of the earth's crust was relieved by bodily lifting, without much crushing or folding, producing the broad and high Allegheny plateau. A few of the crustal folds of northern Pennsylvania are continued into New York as weak anticlines and synclines, but the elevation of the plateau in New York was probably sufficient to keep the enlivened or rejuvenated streams in their southward courses. Possibly the folding of the strata in Pennsylvania was so slow that some rivers even there kept their right of way, as "antecedent" streams.

Succeeding the Appalachian mountain-making, with its relief of strain in the earth's rind, came the long era of the Mesozoic during which the continent appears to have had two long periods of standstill or relative rest from violent epeirogenic movements. Whatever mountains were pushed up into the air during Permian time by excess of uplift over erosion, are believed to have been planed away by the destructive atmospheric forces during the long Triassic-

Jurassic and Cretaceous standstill. The result was a vast plain of erosion, or near-plain, sloping gently to the sea.

The level-topped ridges of hard sandstone which constitute the bold, parallel mountains of New Jersey, Pennsylvania and southward, are regarded as remnants of that ancient but now uplifted and wasted peneplane surface, the weaker, less resistant strata having been eroded away to produce the intervening valleys. This near-plain has been named from the even-crested ridges and called the "Kittatinny," etc., but as it had its finishing touches in Cretaceous time it will be spoken of here as the Cretaceous peneplane.[1]

The Cretaceous peneplane appears to have extended over all of the Susquehanna territory, and probably more widely. Probably the streams were mostly held in their old courses in the lowering land surface with diminishing slopes. The oldest valleys in central and western New York indicate a direction of stream flow to south and southwest, as shown in plate 4. Some of these ancient valleys certainly antedate the present river valleys, and they may date as far back in time as the Cretaceous.

The very thick and weak shales of the Ordovician and Silurian along the belt of the present Mohawk and Ontario valleys encouraged the production of the latter as "subsequent" valleys, by the deepening of the east and west tributary streams. It is possible that these great, dominating valleys were initiated during Cretaceous time, but their great development quite certainly dates from Tertiary time.

Following the long standstill, with erosion and base leveling, of Cretaceous time came the second long epoch of continental uplift, in Tertiary time. It is probable that the great rise in the Tertiary was not a unit or single lift, but by a series of steps with long erosion intervals, and possible peneplanation, and possible oscillations. In the present study the manner and time of the Tertiary uplift is not of primary importance, but the fact of great recent uplift, and probably much greater elevation than we have today, is the important event in the stream history. With the uplift the streams were revived and deeply intrenched their valleys in the elevated peneplane (Allegheny plateau), giving us the present remarkable topography, with its high relief and anomalous drainage. The enlivening of the drainage and the valley deepening gave effect to the varying resistance of the rock strata, which produced diversion even of trunk streams. Tributary and subsequent streams which happened to be fortunately situated in weak rocks or along the strike of the strata deepened their channels more rapidly, and by headward erosion tapped and captured adjaçent drainage. In such manner the primitive Susquehanna was diverted from its southward course into its westward course from Lanesboro, Pa., to Waverly, N. Y. (Compare plates 4 and 5), and the great Ontario and Mohawk valleys were produced by the union of east and west tributaries of the primitive south-flowing trunk streams.

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[1] Some students question the date of the Kittatinny peneplane, especially E. W. Shaw, in paper 23 of the attached list. A review of the literature on peneplanes is there given.

Only yesterday, speaking in geologic terms, the development of the Tertiary drainage was interrupted, forced south, and finally entirely quenched in New York by burial under the Quebec (Labrador) glacier. And when the ice sheet was removed the old valleys were so effectively blocked in places by the glacial drift that the rivers had to cut new channels. The radical changes in the river course may be seen by comparing plates 1 and 5.

TOPOGRAPHY OF WESTERN NEW YORK

The territory involved in this study, and also that of the West Branch, is a part of the great Allegheny plateau, the Catskill mountains surmounting the high eastern front. The altitudes and the slopes of the land surface, however, are poorly indicated by the maps of drainage.

The great changes which have taken place in the altitudes of the rocks and of the land surface may be appreciated by two examples. Rocks in southern New York and northern Pennsylvania which were in the sea near the end of Paleozoic time are now 2000 to 2684 feet above the sea. Conversely, the bottom of Lake Ontario, which must have been at least a few hundred feet above the sea in Tertiary time in order to permit of the flow of the Ontarian river which excavated the valley, is now about 500 feet below sea level.

The Catskill mountains, the highest points more than 4000 feet above tide, are supposed to be remnants of a Jurassic peneplane, while the Cretaceous peneplane is represented in central and southwestern New York by an intrenched plateau averaging about 2000 feet, with points yet higher.

The headwaters of the Susquehanna and its upper tributaries lie in cols (notches or saddles) along the divide between the drainage area of this river system and that of the Mohawk and the St Lawrence.

The following tables give the altitudes and the relief along the principal streams. The figures show feet above tide, being mostly taken from the topographic maps. The figures for the high points or land summits refer to the highest points of the neighborhood, or within a few miles. As the Cretaceous peneplane is about 2000 feet elevation, or perhaps 2100 eastward, the points much above that figure probably represent unleveled masses, "monadnocks," or remnants of the preceding Triassic-Jurassic plane. The figures for the headwaters are for the cols of the lowest of the principal twigs of the drainage. The figures for erosion are suggestive of the minimum intrenching by the streams.

TABLE I

Altitudes at heads of upper tributaries of the Susquehanna river

	Tioughnioga	Otselic	Chenango	Unadilla	Susquehanna	Cherry Creek	Schenevus	Charlotte
High land.........	2 115	2 160	1 720 1 920	1 900 1 960	1 880	2 301	2 427	2 473
Col at headwater...	1 300	1 640	1 150 1 240	1 260 1 220	1 360	1 400	1 500	2 140
Minimum erosion ..	815	520	571 680	640 740	520	901	927	333

TABLE 2

Altitudes at different localities on the north branch of the Susquehanna river in New York

	Otsego Lake	Milford	Oneonta	Otego	Unadilla	Sidney	Bainbridge	Harpursville	Windsor	Susquehanna	Great Bend	Binghamton	Union	Owego	Nichols	Waverly
High land	2 200	2 300	2 200	2 040	2 000	2 000	1 700	2 021	1 940	....	.....	1 820	1 760	1 642	1 556	1 697
River	1 194	1 160	1 070	1 050	1 000	980	970	950	900	875	860	830	800	790	770	755
Minimum erosion	1 006	1 140	1 130	990	1 000	1 020	730	1 071	1 040	....	.....	990	960	852	786	942

In Pennsylvania

	Sayre	Athens	Ulster	Towanda	Standing Stone	Rummerfield	Wyalusing	Laceyville	Meshoppen	Mehoopany	Tunkhannock	Falls	Pittston	Wilkes-Barre	Sunbury	Harrisburg
High land	.....	.....	.....	.....	.....	.....	.....	.....	.....	2 300	2 200	1 600	1 700	2 100	1 300	1 300
River	.....	.....	.....	.....	.....	.....	.....	.....	.....	....	....	570	540	530	430	290
Minimum erosion	.....	.....	.....	.....	.....	.....	.....	.....	.....	....	....	1 030	1 165	1 570	870	1 010

TABLE 3

Altitudes at different localities on the Chenango river

	Morrisville	Randallsville	Earlville	Sherburne	Galena	Norwich	Oxford	Greene	Chenango Forks	Chenango Bridge	Binghamton
High land . . .	1 700	1 700	1 900	1 900	1 865	1 960	1 886	1 584	1 706	1 600	1 820
River	1 270	1 100	1 080	1 050	1 020	1 000	960	900	885	865	830
Minimum erosion .	430	600	820	850	845	960	926	684	821	735	990

TABLE 4

Altitudes on the headwaters of the Chemung river system

	Bennett	Caneadea	Canisteo (head)	Canisteo (Burns)	Cohocton (Wayland)	Twelvemile	Fivemile	(Bath divide)	Mud Creek (Little Lake)	Meads Creek	Post Creek	(Horseheads divide)	SOUTHERN TRIBUTARIES			(Tioga village)
													Cowanesque	Crooked	Tioga	
High land	2 200	2 340	2 220	2 000	2 140	2 163	2 110	1 880	1 680	2 034	2 034	1 647	2 540	2 272	.	2 284
Stream head	.	2 100	2 080	1 200	1 380	1 500	1 460	1 140	1 120	1 480	1 280	910	2 120	1 170	2 000	1 030
Minimum erosion	.	240	140	800	760	663	650	740	560	554	754	737	420	1 102	.	1 254

TABLE 5

Altitudes at different localities on the Cohocton-Chemung system

	Wayland (Col)	Cohocton	Wallace	Avoca	Kanona	Bath	Savona	Campbell	Painted Post	Corning	Big Flats	Elmira	Wellsburg	Chemung	South Waverly	Athens
High land	2 140	2 155	1 923	1 966	1 950	1 880	1 900	1 920	1 800	1 905	1 800	1 780	1 845	1 706	.....	......
River	1 380	1 280	1 220	1 180	1 140	1 100	1 040	1 000	930	910	900	860	800	780		
Minimum erosion	760	875	703	786	810	780	860	920	870	995	900	920	1 045	826		

TABLE 6

Altitudes at heads of tributaries between Binghamton and Elmira

	Nanticoke	Owego (East branch)	Owego (West branch)	Wilseyville	Cattatonk	Cayuta	Wyncoop	Baldwin	Newtown
High land	1 600	2 028	2 009	1 895	1 800	2 000	1 863	1 753	1 872
Lowest col at headwater	1 320–1 400	1 207	1 280	1 000	1 050	1 140	1 320	1 150	1 400
Minimum erosion	280–200	821	729	895	750	860	543	603	472

PRIMITIVE DRAINAGE OF WESTERN NEW YORK

Plate 4

In spite of the radical changes in drainage produced by the several modifying factors acting through many millions of years, with deep erosion and lowering of the area, it appears that a number of valleys have retained or inherited the courses of the earliest drainage. This is most evident in the region of the hard, quartzose, Catskill rocks, in the area drained by the upper Susquehanna and the upper Delaware (plate 4). There can be little doubt that the present streams have the same general direction as the original (consequent) drainage. The opposite extreme is found in the Mohawk, Ontario and Erie basins, where the very deep erosion has destroyed every vestige of the earliest stream flow. In the district south of the Finger lakes and over the upper Genesee valley, where the land degradation has been only moderate, a number of wide, elevated and abandoned valleys with southwestward trend suggest very ancient stream direction (plates 3 and 4).

The earliest (consequent) streams in the western half of New York must have accompanied the first permanent rise of the area out of the interior (epicontinental) sea. The succession of rock strata shows that the progressive land uplift was in general direction from north to south. The vertical oscillations of western New York during Paleozoic time, producing a long succession of marine submergencies and subaerial exposures, have been pictured in a series of paleogeographic maps by Professor Charles Schuchert (21). These maps show that the relation of the rising and exposed land to the receding sea would cause the rivers in western New York to flow in southwestward direction. According to these maps the Adirondack area and the district east of the Ontario basin were permanently raised above the sea in Upper Ordovician time (Schuchert's plate 61), with the oceanic waters on the southwest. But the area south of the Adirondacks and the Ontario basin area, after several burials in the sea with long intervals of exposure, was not permanently lifted above the sea until the close of Devonian time (Schuchert's plates 77-78).

It has already been shown that the remnants of Pocono sandrock on the summit of the Elk hills in northeast Pennsylvania, only 15 miles south of the New York line, indicates that at least the southern border of the State, in the Binghamton district, was submerged in early Mississippian time. The occurrence of Pottsville conglomerate in the southwestern part of the State shows either submergence or very low altitude in Pennsylvanian time (Schuchert's plates 83-84). And during all that ancient time down to at least the Permian the oceanic waters were contiguous on the south, and consequently the drainage of New York must have been south to southwestward across the State.

At the time of that earliest permanent uplift of western New York there was no Ontario basin nor Mohawk valley. The rivers had their sources in Canada and flowed southward, carrying the waste of the exposed land into the receding sea. As the land uplift progressed the rivers extended their courses over the newly-exposed marine deposits, and finally passed entirely across the State into Pennsylvania.

Any hypothetic map of that primitive, Paleozoic drainage would be only a series of lines from Canada southwestward across the western part of the State, and no such map is presented. Plate 4 shows the oldest drainage lines for which evidence is found in the present topography, and the valleys marked by these lines may not be older than late Mesozoic or early Tertiary, although they might have been inherited or intrenched from Paleozoic stream courses. Such inheritance is thought to be the fact for the upper Susquehanna and upper Delaware. The strata of the region are nearly horizontal and fairly uniform over wide extent. No folding of the beds has been sufficient to produce any diversion of the streams. Minor oscillations of the land level occurred during the deposition of the strata, and great changes of level have occurred since the primitive rivers were established; but the uplifts of Permian and of Tertiary time raised the whole region bodily, or as a unit, without causing change in the general direction of stream flow. The upper Delaware and the upper Susquehanna with its upper tributaries are quite surely in their original courses. They have probably merely intrenched their valleys as they were rejuvenated by the continental uplifts.

The northeast by southwest direction of a number of old valleys in the area west of the Susquehanna district above described is significant in this connection. They have been noted at the beginning of this chapter. Some of these wide, old valleys now carry no streams, or only weak and inconsequential ones. They are transverse to the present lines of drainage and are evidently of much greater age than the present master-stream valleys. Only the more conspicuous valleys of this kind are shown in plate 4, but the net of transverse and discordant valleys is shown in plates 2, 3 and 5. Unfortunately two considerable areas in the southwest part of the State are not yet covered by the topographic sheets, or the number of these southwestward lines could be increased.

These old valleys having the direction of ancient stream flow may be divided into three classes: (1) those which still carry streams; (2) those which are practically abandoned by streams; and (3) those in which the stream flow has been reversed. The first class includes the Delaware and Susquehanna valleys, already described, and also numerous shorter valleys or sections of valleys on the west. The second class includes the most puzzling element in New York physiography, the broad, elevated, "hung up" valleys which are not now occupied by effective streams, and in portions by streams of reversed direction. Some attempt was formerly made to explain these "hanging" valleys by glacial erosion of the intersecting ones. These old valleys are themselves, however, more nearly in line with the direction of glacial flow than are the deeper valleys which cut across them. The old drainage lines shown in plate 5 include both the second and third classes, and should be studied in connection with the topographic sheets.

The few exceptions, in the higher ground, to the southwestward direction of the larger valleys are the head waters of the Genesee trunk, but not its tributaries; the Canisteo; the Cohocton-Chemung; and the Cayuta, Catatonk and Tioughnioga. The upper Genesee is reversed (obsequent) Tertiary flow, and the other valleys owe their size and importance if not their origin to forced glacial drainage, as will be described later. The Ontario basin has been lowered by some thousands of feet. The drainage is Tertiary, largely reversed (obsequent), and will be the subject of a later chapter.

On the Canajoharie, Richfield Springs and Winfield sheets it is seen that the line of water parting between the Mohawk and the Susquehanna drainage lies some miles north of the higher ground, and some hundreds of feet lower. The precise divide has been established by the resistance of the combined limestone beds of the Helderberg and the Onondaga, while the higher ground on the south is Hamilton shale. This relationship of the topography to the drainage may have little significance as to the relative age of the valleys, but the south-leading valleys must antedate the Mohawk depression. The prominent notches across the divide and at the heads of the Susquehanna drainage are believed to represent river flow from the Adirondack area before the Mohawk valley was initiated.

A careful examination of the valleys on the north side of the Mohawk depression will show a reasonable connection or relationship in direction between some of those valleys and the upper valleys of the Susquehanna system. This is not attempted in plate 4.

CONDITIONS IN MESOZOIC TIME

Between the date when the primitive southward drainage was established in western New York and the time represented by the drainage shown in plate 5 lies a vast interval of tens of millions of years, much of which is in mystery. This includes all of the Permian Period, the long Mesozoic Era, and most of the Tertiary Period. In physical changes this immense duration covers the great Appalachian Revolution, with its long epoch of mountain-making, the destruction of the mountain ridges by subatmospheric erosion and the supposed reduction of the area under study to a near-plain, then the uplifting of the area in Tertiary time, with the rejuvenation of the streams and some diversion of their courses.

The changes in drainage effected by the more recent, or Tertiary, uplift will be considered in the succeeding chapters. The larger part of the history, during Permian and Mesozoic times, is quite unknown, and here is the chapter in the dramatic story where we must appeal to imagination and theory.

The first serious interference with the primitive drainage must have been the Permian uplift. Then the Atlantic border region was pushed to the northwest some 15 miles, producing the crushing, crumpling and folding of the Paleozoic sediments, as shown in the Appalachians. Some of the deep-seated material of the earth's rind, in the plastic zone beneath the belt of folding, appears to have been pressed northwestward in beneath the less folded belt, producing the bodily uplift of the Alleghany plateau. This plateau uplift must have been sufficient to preserve the superior elevation of the upper Susquehanna area, as the streams appear to have preserved their southward courses into Pennsylvania.

The immediate effect on the rivers in Pennsylvania of the surface folding in the Appalachian belt is a difficult but interesting problem (see Davis' paper, No. 5). If the ridges rose so slowly that the Susquehanna and other transverse streams kept their right of way and cut "water-gaps" across the ridges then we should call the rivers "antecedent." This would be the simplest, but probably not the true, explanation of the transverse relation of the Delaware, Lehigh and Susquehanna rivers to the folds. The alternative explanation attributes the river courses to adjustment and diversion during the Mesozoic peneplanation and the Tertiary uplift. If the Susquehanna was diverted by the Permian uplift, however, it should have swung southwestward, parallel to the folding, and it is difficult to imagine how it could ever have been thrown back across the mountain belt. It is reasonable to assume that the trunk streams in New York at least retained their general direction during Permian and Mesozoic times, and that the serious diversions took place in Tertiary time. The more difficult and elusive history of the drainage in Pennsylvania is not strictly a part of the present study.

During Mesozoic time it is supposed that our New York area was suffering continuous erosion during two stages of peneplanation and was eventually reduced to a low, rolling surface graded to sea level. Beyond this we have no idea of the details in the history.

The higher hills in any district of western New York have such a general correspondence in altitude that from elevated viewpoints the horizon is a remarkably smooth and level line. This fact is the chief argument for the peneplanation theory. In casual examination of one of the topographic sheets of a hilly country the correspondence in height of the higher hilltops may not be evident. The differences in height must be compared with the total elevation. Some idea may be had by averaging the high points given in preceding tables (pages 16–19) and comparing the variations with this average altitude. The best illustrations of the peneplane is found in the even-crested mountain ridges of Pennsylvania, in the Harrisburg district, for example.

It does not appear likely that there could be serious change in the courses of the rivers during the Mesozoic peneplanation. The stream gradients were decreasing and the causes of diversion were less effective. It appears probable that the drainage at close of the Cretaceous was similar in direction to that at the close of the Permian. Plate 4 is perhaps a map of Cretaceous valleys.

DRAINAGE ADJUSTMENT IN TERTIARY TIME

Mohawk Valley; Susquehanna River Beheaded

With the above discussion of the physiographic history of the area we must now try with the help of the scientific imagination to visualize the events or changes by which the Susquehanna-Tunkhannock river of more ancient time became the great Susquehanna-Senecan river of late Tertiary time.

The original Susquehanna had its source, and its upper tributaries somewhere in the Adirondack district. It was beheaded, or its upper waters cut off, by the creation of the Mohawk valley. The date of this accident to the Susquehanna is not precisely known. Most physiographers assign the Mohawk valley to the Tertiary period, which must certainly be true for the larger part of the erosion. This valley is subsequent to the Hudson, so that the question of age may relate primarily to the Hudson. For our present purpose the precise date, whether late Mesozoic or early or middle Tertiary, is not essential.

As the Mohawk valley is wholly erosional, being carved out of Paleozoic strata with only moderate dip, it is evident that the higher strata on the south side of the valley once extended northward to and perhaps over the southern Adirondacks. A great thickness of relatively weak rocks encouraged the headward growth of the initial Mohawk along the strike of Ordovician shales until it had extended its domain northwestward and captured the headwaters of the Susquehanna that had been flowing southward across the territory. It has already been suggested that study of the stream valleys north of the Mohawk may enable the student to correlate those valleys with the present Susquehanna headwaters.

Except the Schoharie creek the southern tributaries of the Mohawk are very short. The Oriskany and Sauquoit creeks belong essentially to Ontario drainage, because the preglacial head of the Mohawk appears to have been at Little Falls. The present divide, at Rome, has been established by glacial interference. The south wall of the Mohawk valley is relatively steep and narrow, suggesting a southward migration of the valley; and some cols are not in the line of the high ground of the general divide, but lie somewhat northward, on the south wall of the valley, being determined by the hard limestones as already noted.

Westward Diversion of the Susquehanna

The maps show a radical change in the direction of the river after it enters Pennsylvania. At Lanesboro and Susquehanna villages the river makes an abrupt turn from south to west and northwest. This long ago gave suggestion of an abandoned channel south of Lanesboro. In 1908 the writer examined the district and found the old channel marked by a deep notch or "wind gap" across the divide. This pass is at the Rosskelly four corners, 5 miles south of Lanesboro, and in Jackson Township, and is the col at the heads of the north-flowing Canawacta and the south-flowing Tunkhannock creeks. The pass has been swept by glacial waters, the outflow of a glacial lake in the Canawacta valley. A well-marked bowlder-strewn channel leads south from the road corners (plate 26). The width of the channel is estimated at about 400 feet, but the valley proper is one-fourth of a mile wide and the hills rise 400 or 500 feet above the pass. The altitude is given by I. C. White (2, page 18) as 1600 feet. Three aneroid measurements at different times from distant benches have made it 1540, 1535 and 1568.

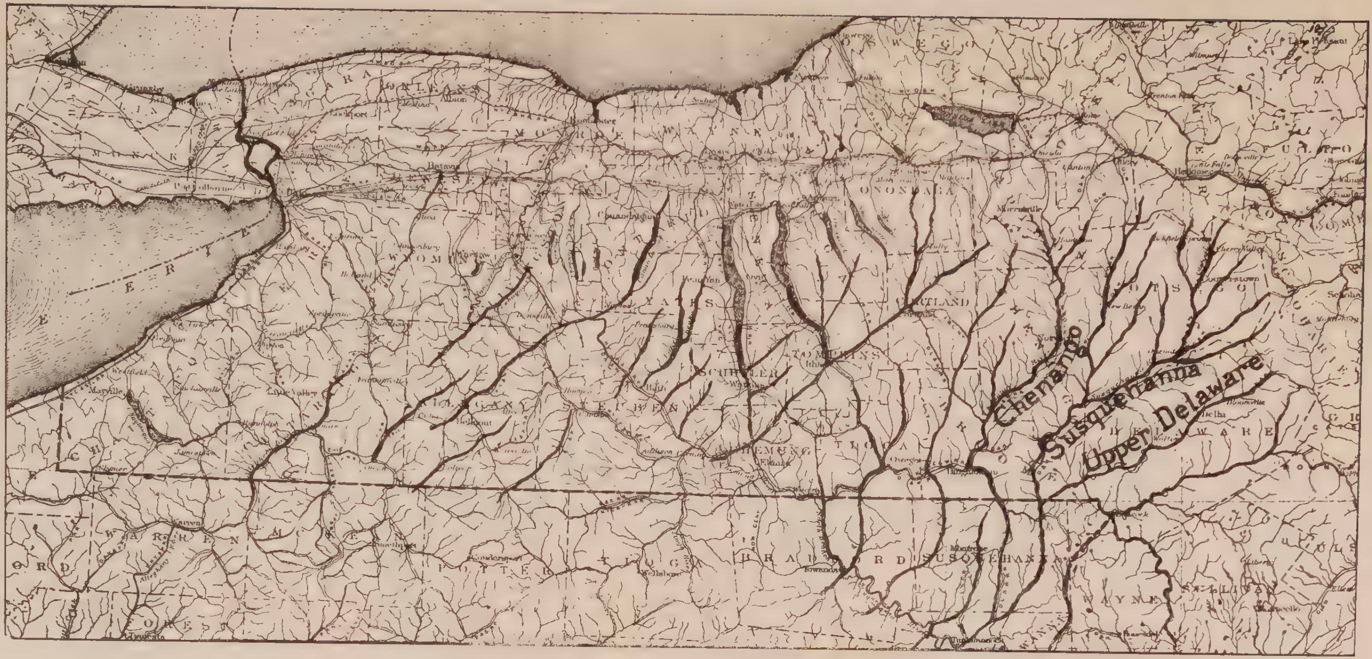
The Tunkhannock creek, heading at this col, flows southwest and enters the Susquehanna river at Tunkhannock village. The great viaduct of the Delaware, Lackawanna & Western railroad crosses this old course of the ancient Susquehanna river at Nicholson (plate 27).

We have no topographic map of the quadrangle covering the Jackson wind gap but fortunately the adjacent sheet on the south is published, the Dundaff sheet (plate 9), which shows 10 miles of the Tunkhannock valley, from above South Gibson to near Nicholson. This sheet also covers the Elk hills, capped with Pocono sandstone, at an elevation of 2684 feet. This summit is only 4 miles from South Gibson, where the Tunkhannock creek has an altitude of 1000 feet. The original extent of the Pocono beds has been noted, and it is certain that the valley trenching at South Gibson has removed at least 1684 feet of hard Catskill and Pocono.

Reference to plate 5 shows that the upper Delaware was a tributary of the Susquehanna, joining the latter just south of the state line. The present divide between the two rivers is at Gulf Summit, where the Erie railroad found the lowest pass from the Susquehanna valley over to the Delaware.

This map also shows three parallel south-flowing rivers west of the Susquehanna, being the Chenango river, the Nanticoke creek joined with the Otselic creek, and the two branches of the Owego

Plate 4



Courses of Very Ancient Drainage as Suggested in the Existing Valleys

creek. Of course this mapping is hypothetic, but it has good basis. The greatest uncertainty relates to their southern courses, in Pennsylvania. Today they are branches of the west-flowing stretch of the Susquehanna.

As the Jackson wind gap is a relic of the southward flow of the ancient Susquehanna, so the southward continuation of the ancient Chenango river is probably marked by the notch in the divide, 2 miles southwest of New Milford, Pa., and 6 miles northeast of Montrose. The low pass is utilized by the Delaware, Lackawanna & Western railroad for its main line between Scranton and Binghamton. In his study of Susquehanna county for the Second Geological Survey of Pennsylvania, Dr I. C. White noted this pass and described it as follows:

> In Susquehanna county there are two or three instances in which streams are now flowing in opposite directions, with their heads at a very low divide in the floor of probably ancient waterways.
>
> One of these is the old valley in which Martins creek flows southward and Salt Lick creek northward. The divide between the two streams is a low drift deposit in a comparatively narrow valley, 500 feet below the general level of the uplands (2, page 28).

On pages 105–106 of the same report Doctor White again refers to this pass. He gives the altitude as 1175 feet.

The map (plate 4) shows two other ancient rivers west of the Chenango with similar southern drainage. One of these is made of the present Otselic and Nanticoke creeks north of the present Susquehanna, and the Choconut-Wyalusing creeks south of the Susquehanna, and crossing the latter at Union between Binghamton and Owego. The other hypothetic stream ties together the two branches of the Owego creek in New York and the Apalachin creek in Pennsylvania, crossing the Susquehanna at Owego.

Doctor White did not fail to recognize these two passes. In his report (2) he says:

> At the heads of Choconut and Apalachin creeks similar low, drift-filled divides are seen separating their waters from those that go southward into the Wyalusing (page 29).
>
> Near the southern line of this area (Apalachin township) there is a low divide between the head waters of the Apalachin and those streams which carry the drainage southward and southwestward into the Wyalusing; here the aspect of the country looks very much as though the northern ice sheet had cut down the divide to such an extent that the morainic drainage may have passed southward across it into the Wyalusing valley (page 81).

The writer has visited the passes described above and finds that Doctor White's suggestion of glacial drainage across the cols was based on good observation, for they carried the waters of local glacial lakes. The divide between the north-flowing Choconut and the south-flowing Wyalusing creeks is near St Joseph's Church, about 3 miles east of Friendsville, Susquehanna county, Pa., with aneroid altitude of 1275 feet. This is in a notch about 400 feet deep, and is a swamp col that was the outlet of the Choconut glacial lake.

The divide between the Apalachin creek and the north branch of the Wyalusing is at "Bear Swamp," 2½ miles northwest of Friendsville, in a deep, narrow, dark valley, about 1225 feet by aneroid, and between hills rising at least 600 feet. This is also a swamp col, and was the outlet for the Apalachin glacial lake.

The general process by which these three south-flowing rivers, and the Susquehanna as a fourth, were dissected and the upper waters thrown into westward flow is quite evident and was effected in a similar manner to the capture of the upper waters of the Susquehanna by the Mohawk, and their diversion to eastward flow, so these four rivers were beheaded by a stream developed from east-and-west tributaries lying along the south border of the State, and which had cut down into the weak Chemung shales, lying beneath the hard Catskill sandstone. Between the Chenango and the Susquehanna the operation is clear. The abandoned Jackson pass is now at least 1550 feet. The New Milford pass, the path of the old Chenango, is about 1175 feet, or 375 feet lower. A west-flowing tributary of the Chenango, with its greater fall, had advantage over any opposing tributary of the Susquehanna. By headward erosion the former eventually tapped the Susquehanna and added its waters to the Chenango, or to whatever waters had previously captured the Chenango. By similar diversion all the south-flowing streams between Lanesboro and Waverly were turned westward.

We can not be sure of the order in time of the capture and westward diversion of the rivers, especially because we do not know where the most western control was located. The greater Susquehanna with its glacial flood has deepened its path; and we have no Pennsylvania topographic sheets of the wide area involved until within 15 miles of Pittston.

It is possible that the beheading process began on the west and progressed eastward, and that the Susquehanna was the last capture. One reason for this thought is that the Martins creek valley, the old path of the Chenango, is not as capacious as that of the Tunkhannock, the path of the original Susquehanna. Another point is that the cols east and west of Friendship are higher than the New Milford pass, while the divides at Montrose and all other passes are still higher. The result of the stream changes, however, is more important than the exact sequence.

Another interesting problem is the date in geologic chronology when the westward diversion of the Susquehanna occurred. Undoubtedly it represents a lively rejuvenation of the general drainage, and this, of course, implies an uplift of the wide region. If the even skyline of the high ground represents a peneplane of the Mesozoic erosion, then surely this stream diversion was Tertiary, and probably in early Tertiary. It most certainly was the continuing effect of the earliest land uplift succeeding the peneplanation of the Allegheny plateau.

We have a suggestion of relative duration in the three episodes of erosion, the two relating to shifting drainage and the previous peneplanation. In the district of Jackson pass the high ground supposed to represent the Cretaceous peneplane averages about 2100 feet in altitude. The Elk hills, close by, rise to 2684 feet, and are apparently a monadnock in the old plain. This gives at least 584 feet for the Cretaceous erosion, in hard Pocono and Catskill sandstones. At the Jackson gap the old Susquehanna river intrenched its channel in the Catskill sandstone of the peneplane about 550 feet (2100–1550) before its diversion. At the village of Susquehanna the present river is about 890 feet, hence since the diversion the river has intrenched about 660 feet, partly in Chemung shales. This later erosion includes the scouring by the first glacial flood. Using round numbers we have about 600 feet of general land erosion, nearly the same for the valley cutting in Catskill sandstone by the Susquehanna before its diversion; and something more than 600 feet of downcutting in partly weaker rocks since the diversion. The Cretaceous peneplanation represents vastly greater time than the valley trenchings.

Ontario Valley; Reversal of Primitive Flow

The primitive (consequent) drainage across the Paleozoic coastal plain which occupied the entire area of the present Ontario basin must have been southwestward toward the retreating Mississipian sea. This stream work began as soon as the area was exposed to the atmosphere, perhaps in mid-Devonian or later Devonian time.

All traces of this early drainage has been destroyed by the deep erosion of the strata over all of central and western New York. In plate 4 no attempt has been made to indicate that ancient stream direction, which could only be suggested by arbitrary lines drawn from Canada across Lake Ontario and western New York. The courses of the Genesee river and the valleys of the Finger lakes may have no definite relation to the early drainage.

The physical changes over the western part of the State from that hypothetic, consequent drainage down to the time of the Preglacial drainage, shown in plate 5 are unknown, yet this interval covers the vast geologic time from the Devonian to the late Tertiary. We see the final result of the great oscillations in the altitude of the continent and of the changes in the drainage in the present gross topography and the larger stream valleys, but the long and complex process is in mystery.

The wide Ontario valley is the great positive topographic feature of the western part of New York, and it became the dominating factor in the stream flow. A full discussion of its origin will involve a discussion of the origin of the basins of all the Great lakes, or the preglacial history of the St Lawrence river system, which is one of the unsolved problems in American geology; and such study is not intended in this writing.

We know that rivers are the valley makers, and it is certain that the Ontario basin is a valley of erosion, carved out of the thick and weak Ordovician and Silurian strata by atmospheric agencies. Recent land warping and northward uptilting may partly account for the lake, or the basining, but not for the valley. The reader may find it difficult to realize that the deep valley, with the bottom of Lake Ontario now almost 500 feet below sea level, was excavated by a land stream flowing to the sea. Yet this is a small example of the up-and-down (epeirogenic) movements of the continental surfaces. The thickness of the oceanic sediments beneath the city of Rochester is quite 3100 feet, the lowest rock being sandstone, a shallow-water deposit. This proves a net subsidence of about 3000 feet. A thickness of at least 1000 feet of marine sediments has certainly been eroded from the locality, which makes the subsidence at least 4000 feet. The subsequent net elevation has been the thickness of the strata removed plus 500 feet, the present elevation of the place where the deep boring was made, or 1500 feet. It appears probable that the erosion of the strata at Rochester may be 2000 feet, in which case 1000 feet more must be added to the figures for both the sinking and the rising of the land. These figures are only net, and do not take into account the unknown but probably large uplift in Tertiary time, before the Pleistocene ice cap weighted down the northeastern part of the continent. On the basis of only 1000 feet of erosion at Rochester the excavation over the basin of Ontario is more than 2000 feet. This is, however, moderate as compared with other examples of deep erosion, like the valley of the Colorado river.

The development of the great dimensions of the Ontario as a subsequent valley was due to the outcropping along the east and west belt of the very thick and nonresistant shales of the Silurian and Ordovician. On the meridian of Cayuga lake the thickness of the strata from the Trenton limestones up to the Portage sandstones is over 5000 feet; and of this depth 4500 feet are shales, with only some 350 feet of limestone and 250 feet of sandstone. With uplift of the area it was inevitable that this belt of weak rocks would invite the production of a great transverse subsequent valley.

While it is certain that the Ontario valley was occupied by a great, dominant master stream, which we may call the Ontarian river, it is not positively known if it reached the sea by way of the St Lawrence valley or by westward flow to the Mississippi embayment. For various reasons which may not be recited here it is believed that the flow was westward, and it is so represented on the map (plate 5). We may now picture the evolution of the Ontarian river. In the same manner that the Mohawk river was evolved, by linking of east-and-west tributaries of the south-flowing primitive or consequent rivers, until the latter were captured and diverted, so was the Ontarian river evolved. Favoring the westward diversion of the streams, it may be noted that the rocks had less resistance on the west, becoming less quartzose and with finer grain, that with the uplifts of both Permian and Tertiary time there appears to have been produced a westward decline of the land surface toward the Mississippian lowland. These probable conditions gave the west-flowing tributaries an advantage over the eastward streams, and both sets had advantage over their trunk streams with southward flow because they were flowing along the outcrop or strike of the weak strata. By normal stream adjustment the more active west-flowing streams captured the Canadian rivers and turned them all into the westward flow of the master stream.

We can only surmise when the Ontarian river was established and the valley outlined. It might be suggested that the Permian uplift, diminishing northward raised the southern belt of New York more than it did the Ontario area and that this tended to check the south-flowing primitive streams and gave advantage to the westward flow. This would imply that the Ontario valley was initiated in Mesozoic time. Probably few geologists will admit so early a beginning for the Ontario valley. The problem involves the northward reach of the Mesozoic peneplane. Whatever the geologic date for the birth of the Ontarian river we may be sure that after it was established no subsequent continental movements diverted its flow or interrupted the valley erosion until glacial time.

We now turn to more definite history, the reversal of drainage in the western part of New York. The east and west Ontario valley had, of necessity, a south bank or north-sloping wall, and north-flowing streams were developed. The remainder of the Preglacial history relates to this northward drainage.

As the Ontario valley widened, this northward, reversed or obsequent drainage extended its control southward. By headward cutting it ate more and more deeply into the plateau of southern New York. In the erosion of a region of inclined beds, like the area involved, the divides shift in the direction of the dip, or down slope. The north-flowing streams, cutting across the outcrops, had advantage over the original south-flowing streams lying on the gently inclined beds. With continued deepening of the Ontario valley its southern tributaries gnawed back into the highland of New York until the Ontario drainage had extended its mastery over nearly all of New York west of the Mohawk and the Delaware, and over much of northern Pennsylvania. The chief exception is that of the Allegany, which flowed northward into the Erigan river (7). The Erie valley probably has a physiographic history similar to that of the Ontario. It must have been a magnificent stream which in preglacial time rolled through the Ontario valley, tributary to the Mississippi.

The Finger lakes lie in valleys which, with possibly two exceptions, belong to the north-flowing reversed drainage. A number of the obsequent valleys do not hold lakes. From the Tonawanda valley on the west to the Onondaga valley on the east we count fifteen parallel valleys, with several other valleys farther east, around to Oneida lake, which are also part of the Ontarian obsequent drainage. Probably this is the most remarkable series of parallel valleys in the world.

Plate 5 shows the reversed drainage of late Tertiary time, but the description of the map is deferred to a later chapter.

It is possible that some of the valleys of the Finger lakes district are in the lines of the primitive south-flowing streams; or, in other words, that some of these north-sloping valleys are the intrenched inheritances of the original consequent valleys, with the direction of flow reversed. The depth of erosion in the region is so great, however, that no statement can be made with confidence.

The present divides at the heads of these valleys (plates 1, 2 and 3) are clearly due to glacial filling, the preglacial divides being far south (plate 5). The Genesee valley, heading in Pennsylvania and flowing north entirely across New York, is the best surviving example of the late Tertiary drainage. Even the damming and diverting effect of the ice sheet, so successful with other valleys (plate 6), could not reverse the flow of this river; although in three localities it was so obstructed that it found new rock channels, producing the picturesque canyons at Portage, Mount Morris and Rochester (32, 40, 41).

Like the Ontario valley the trenches of the Finger lakes are surprisingly deep. Cayuga lake has a depth of 435 feet, or 54 feet below sea level. Seneca lake is 618 feet deep, or 175 feet below tide. These figures probably do not give the actual depths of the preglacial rock valleys, as there may be considerable depth of glacial filling. It is reported that at Watkins, the head of Seneca lake, a drill has pierced to the depth of 1200 feet without finding rock; which carries the rock bottom down to over 757 feet below sea level, or lower than the measured depth of Lake Ontario. Doubtless there is considerable filling in Ontario.

The former suggestion that the excessive depths of Seneca and Cayuga lakes was produced by glacial erosion was partly based on the absence of northward extension of their valleys toward Ontario, although Sodus bay, and bays eastward, do give suggestion of buried valleys. North of the lakes from Seneca eastward the preglacial river channels are buried under morainal drift and capped by drumlins.[1] Only systematic probing by the drill can map the drift-buried topography and reveal the courses and depths of the rivers which were the predecessors of the Finger lakes, and prove if they were graded to the Ontarian river.[2] This might show the existence of cataracts or cascades where the streams crossed the heavy limestones, Onondaga-Helderberg and Niagara, and the sandstone beds of the Medina.

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[1] Drumlins of Central and Western New York, New York State Museum Bulletin 111, 1907.

[2] Such exploration of the concealed geography would be appropriate educational work for the State.

West of Sodus bay only one visible preglacial valley leads northward to the Ontario. This is the capacious Irondequoit valley, close east of Rochester. It appears probable that the weaker streams of the northward drainage were thrown into east and west courses along the belt of outcrop of the very weak Salina shale, similar to the present drainage. In plate 5 the northward drainage is hypothetically gathered into four great rivers, the Genesee-Irondequoit, the Susquehanna-Seneca, and rivers of less certain location for the eastern territory.

Northward Diversion of the Susquehanna River

The most notable and radical element in the Tertiary drainage, shown in plate 5, is the northward course of the Susquehanna. That the great Ontarian river grasped the drainage of central New York, the district of the Finger lakes, appears natural; and that it seized the Genesee is a fact of present time. But that it was so greedy and powerful as to reach far south and subdue the Susquehanna is surprising. As a fact, this is not yet absolutely proven, in the lack of sufficient drill data in the stretch from Waverly through Elmira to Horseheads. But all the data acquired thus far from well borings and all the physiographic features strongly indicate such northward flow. If we could clear out the drift filling of the valleys from Owego around to Horseheads it appears quite certain that the Susquehanna would today take the north course through the Seneca valley. Adding to this probability it should be recognized that the rather narrow and youthful channel of the river from Towanda south to Pittston has been deepened to some considerable, but indeterminate, amount by the glacial flood, since Tertiary time.

The significant physiographic features of the Waverly-Elmira district are fairly shown in the maps (plates 3, 10 and 11). The Elmira quadrangle is well known to geographers as a classic example of drainage diverted by glacial interference. Unfortunately the territory in Pennsylvania, the Sayre and Towanda quadrangles, is not surveyed. Here is a wide, triangular area between the Susquehanna and Chemung rivers with the conspicuous, isolated Spanish hill rising out of the flat plain. The full understanding of the geography requires knowledge of the glacial history, which is treated in a later chapter.

The valley of the Chemung river between Elmira and Waverly is evidently a drift-filled preglacial valley. It is fully as capacious as the Susquehanna valley above Waverly, and is not the product of glacial nor present drainage. The Chemung river now lies in this stretch because of glacial diversion and is not responsible for the old valley. The preglacial path of that river lies buried in the wide valley at Big Flats and swinging north at Horseheads, while its new channel, for which it is only partly responsible, is the narrow valley southwest of Elmira.

The dimensions and form of the wide valley at Elmira and Horseheads, with the uniform curve of the steep east wall and the truncation of the spurs near Horseheads, indicate the work of a heavy stream. After reading in a later chapter of the glacial waters the reader might question if these features were produced by the southward glacial flow from central New York. Effective erosion by the glacial waters was limited, however, to a brief episode of weak flow. During the advance of the ice sheet the southflowing stream drained a lake, probably corresponding to the Lake Newberry of the ice retreat, but with outlet farther south, and it was not provided with abrasive tools. During the recession of the ice front the valley was occupied by the Elmira lake, and was receiving its filling of drift. It was only when the ice front during its advance was passing over the locality that the waters had cutting power, and then the volume was small.

The great depth of the Seneca valley is important, not only with reference to its relation to the Susquehanna river but as bearing on the great depth and peculiar form of the other Finger lakes valleys, especially Cayuga. The suggestion is that of abrupt rejuvenation, in very weak rocks, shortly preceding glaciation.

The singular character of the Susquehanna valley below Towanda has an important bearing on the history. In plate 5 the divide between the north and south drainage is drawn at Towanda. From that point south to Pittston the valley has a character unlike any other stretch in the whole length of the river. Swinging in wide meanders, apportioned to a large river, it is lying against high cliffs on nearly every outer or tangential curve. The cuttings for the Lehigh Valley railroad have only emphasized the cliffs on the east side of the river. Above Towanda the river is above its old bed, flowing in drift filling, and rarely cutting the valley sides. The gradient of the Towanda-Pittston stretch is less than that elsewhere, except the Binghamton district. Plate 5 gives basis for the doubt that this part of the present Susquehanna valley carried the flow of the earliest southward drainage. We do not know when this stretch was developed so as to acquire the river. It is certain that it carried the tremendous glacial flood, during both the oncoming and the waning of the glacier (plates 6, 7 and 8), and the present flow since glacial time.

It appears most probable that no flow of the upper Susquehanna and its tributaries ever passed south past Towanda until forced there by the oncoming ice sheet. This implies that the westward diversion of the Chenango and Susquehanna was directly into the northward flow through the Seneca valley, the Senecan-Ontarian river.

This problem would require no discussion if we knew the slope of the bottom of the old valleys, beneath the drift filling. The well records now available are not conclusive, although suggestive. The figures depend too much on the memory of the drillers, and the borings are commonly not in the middle of the valleys or along the supposed axis of the ancient valleys. The following figures are for the elevation of the rock above sea level, calculated from the depth of the well and the elevation of the ground surface. Only the more reliable and significant data are given, and the figures are not precise.

	Elevation in feet above rock
Binghamton, lowest record of rock surface	686
Owego, three wells near the south side of the valley	600
Union, rock at	580
Waverly, no records for the middle of the valley	
Chemung, no wells	
Wellsburg, no wells	
Southport, in valley of Seely creek	775
Elmira, two wells close to the east wall of valley	734
North Elmira, no rock at	749
Horseheads	550
Millport, no rock at	524
Watkins, no rock reported at 750 feet below tide	
Sayre, one well	565
Athens, one well	610
Milan, one well	692
Ulster, one well	600

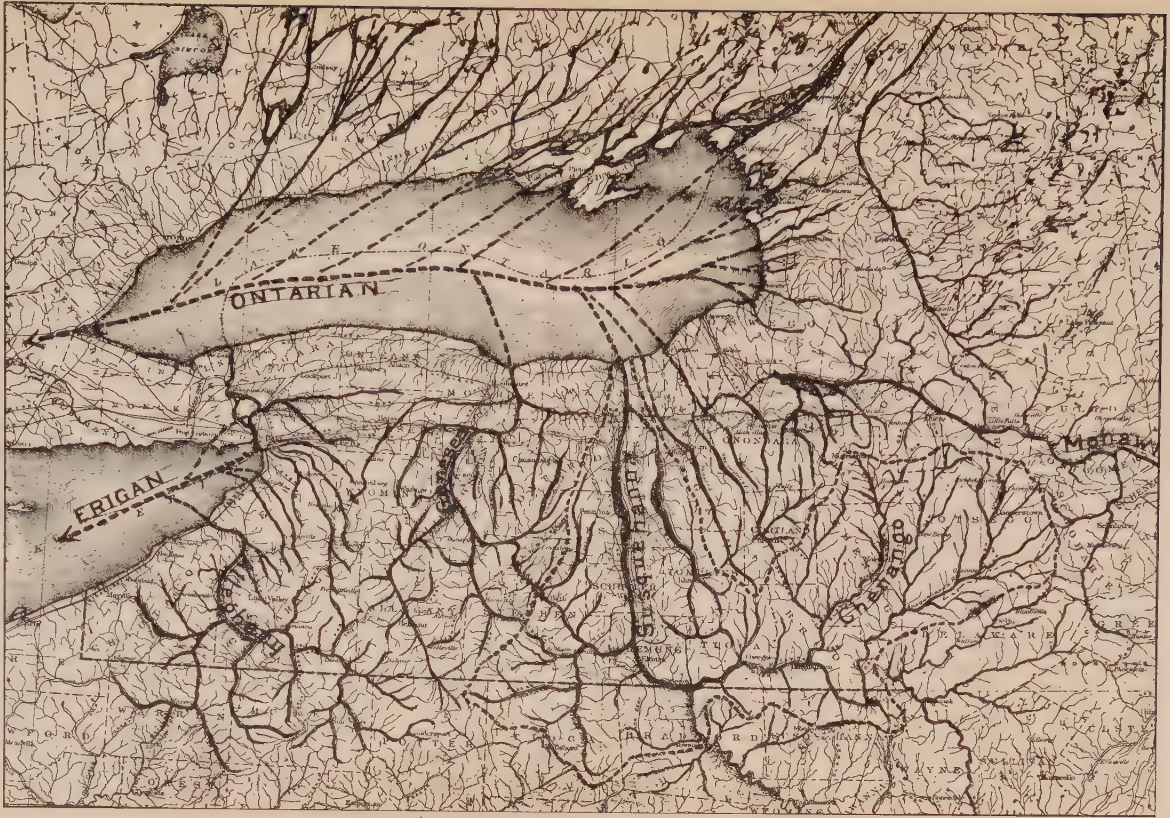
Review of the Tertiary Drainage

Plate 5

Several elements in this map, not directly related to the Susquehanna river deserve notice.

The wonderful character of the Tertiary drainage can not be appreciated without comparison with the other maps, especially plates 4 and 6. Accuracy in detail of the stream lines is not claimed,

Plate 5



PROBABLE DRAINAGE OF LATE TERTIARY TIME

A broken line bounds the drainage area of the ancient Susquehanna. Other broken lines mark hypothetic courses of Tertiary rivers

but the main elements are quite certainly true. The remarkable changes from the primitive drainage are better justified when we realize the enormous interval of geologic time. It might be interesting if some of the intermediate stages of the drainage between the Paleozoic and the late Tertiary could be mapped. While this might be plausibly done for some districts it would be so hypothetic and involve so much of pure assumption as not to be worth while for the whole area.

The southward reach into Pennsylvania of the tributaries of the Erigan and Ontarian rivers is clearly shown. A line of waterparting is drawn only for the Susquehanna boundary.

The Tertiary Alleghany (7), reached the Erie valley by the way of the lower Cattaraugus valley.

Between the Alleghany and the Genesee control a number of smaller streams had separate northward courses, represented today by the Cayuga, Cazenovia, Buffalo and other creeks, which with the Tonawanda were the headwaters of the Erigan river.

Two of the parallel Finger lakes valleys are represented with southward flow, the original stream direction, Canandaigua being tributary to the Genesee and Keuka to the Susquehanna. All the other central New York valleys have northward or reversed direction.

A broad valley which today is filled with drift, forming a divide at Wayland, west of Dansville, carried the Canandaigua-Dansville river. This master stream drew on southern territory, including the upper part of the present Canisteo valley, and south of Mount Morris it joined forces with the upper Genesee. This enlarged Genesee river was a rival of Susquehanna-Seneca. North of Avon the latter's course is obscured by the drift, but the only possible course appears to have been eastward along the weak Salina belt and then northward by the deep and capacious Irondequoit valley, east of Rochester. The present course of the Genesee north of Avon with its handsome canyon at Rochester, is clearly postglacial, as are the gorges at Portage and Mount Morris.

The belt of thick and very weak Salina shale, forming the surface outcrop from Niagara river to Oneida lake, passing south of Rochester and through Lyons and Syracuse, forms today a shallow depression having Onondaga limestone as its south border and the Niagara limestone as its north rim. Evidently this depression is an inheritance of the Tertiary topography, which has been only partially filled by drift, for with only two notable exceptions all the streams which enter the depression follow it either east or west. The Niagara and Genesee rivers cross the sag by postglacial channels. Practically all the drainage which enters this belt becomes tributary to either the Niagara, Genesee or Oswego rivers, all three being in postglacial rock canyons.

This Salina outcrop depression was a controlling feature in Tertiary time, for only a few old valleys trench the Niagara-Medina scarp to enter the Ontario valley. The only ones in New York are Irondequoit, the buried valley which probably is represented by Sodus bay, and perhaps valleys correlating with Port and Fairhaven bays. The three latter are obscured by glacial drift and superposed drumlins, but are the only reasonable outlets for the waters of central New York.

The present Cohocton valley (plate 24) is represented as bisected by a divide above Bath, which threw the Keuka outflow into the Susquehanna.

The Cayuga valley, comparable in dimensions with the Seneca valley, presents a difficulty in the mapping. It claims some territory on the south but has no heavy tributaries. The broad northeast-by-southwest " hung-up " valley, having Cortland at the middle (plates 2 and 4), has no low outlet at Ithaca, and no sufficient escape southward. The Tertiary flow apparently dissected this ancient valley, and the upper part is here carried northward past Tully to the Onondaga valley. It is a choice between this and the Owasco valley. The Cayuga flow is added to the Susquehanna-Seneca river.

The break between flow to the Mohawk and to the Ontarian is made at Little Falls (25), and the Rome-Oneida lake trunk river is sent west to Cross lake and then northwest through Fairhaven bay. This is the most uncertain district to map. Possibly all the eastern waters joined the Susquehanna-Seneca river. The reader may properly try to make some other disposition, for the region is all covered by the excellent topographic sheets. Certainly we must await the revelations of the drill.

The drainage of the western Adirondack area is gathered into the Black river which is sent northeast down the St Lawrence valley. The latter valley has been so scoured by the ice abrasion that the old stream features are gone. For the territory east and north of Lake Ontario Wilson's mapping in paper 18 is practically followed.

The glacial interference which is responsible for the remarkable change from Tertiary drainage to the present hydrography is described in the next chapters.

PLEISTOCENE HISTORY OF THE SUSQUEHANNA RIVER

Introductory Statement

Geologists who are conversant with the area of the Great lakes and the Mississippi valley are confident that more than one ice sheet of Pleistocene time invaded that territory. This has suggested or encouraged the belief in multiple glaciation over New York and New England. The writer is inclined to doubt the validity of this view and to believe that all the glacial phenomena of New York, New England, eastern Pennsylvania and New Jersey have been produced by a single ice invasion, that of the Quebec (Labrador) glacier, of the closing epoch of the glacial period. Considerable oscillations of the ice front are probably responsible for features which have been interpreted as records of distinct ice sheets.

The problem of unit or of multiple glaciation over New York need not be solved, however, for our present study, because the effects upon the drainage of any repetition of glaciation would probably be cumulative. Glaciation did not change the large topography of Tertiary time nor the controlling lines of ultimate outflow, which in New York are the Mohawk valley and the Susquehanna escape. It is a fair assumption that any succession of ice sheets would probably have similar directions of flow, and similar alignment of their borders; and quite surely so if they had their centers or feeding-grounds in the same region. For the Quebec glacier, the only ice for which we have any clear evidence in New York, this center of accumulation is apparently between James bay and the St Lawrence valley. For the purpose of this writing we assume only one episode of glaciation.

The first effect of the invading ice sheet was to block any northward drainage and to force such waters into other and higher outlets. During the waning of the ice body and the recession of its margin the damming effect on the rivers was similar, but in reverse order. The south-leading streams were greatly augmented in volume, and their channels greatly deepened and enlarged. The dominant south-leading valleys of the present drainage which are discordant with both the primitive drainage (plate 4) and with the Tertiary flow (plate 5) owe their prominence to the forced glacial drainage. These lines are shown in plate 6.

Two other principal effects of the glacier were the local filling of some old valleys, thus diverting the stream flow, and the shifting of divides. In north and south valleys the divides were necessarily moved northward, or toward the ice. The most remarkable change of this sort is seen in plates 5 and 1, where the south limit of the Ontario basin is shifted from northern Pennsylvania to the present head of the Finger lakes. This was accomplished by heavy morainal filling and not by headward erosion of the flooded streams.

On the Susquehanna system the main effects of the glacial interference were the turning of the river southward at Waverly, and the addition of territory by the Canisteo, the Cohocton and the Tioughnioga creeks. The head waters and upper tributaries, or the river above Waverly, were not seriously changed by the glacial occupation.

The Pleistocene history of the Susquehanna river involves both New York and Pennsylvania; and the features are as interesting and important in Pennsylvania as in New York. Indeed, the lakes and the high-level deposits in New York were partly dependent on the barriers of drift in Pennsylvania, and the story can not be told for New York without some account of the events down the river. In interstate comity, however, it is desirable that as far as practicable each state should publish the story of its own province. The reader who desires the glacial history of the entire river will obtain paper 43 of the list of writings.

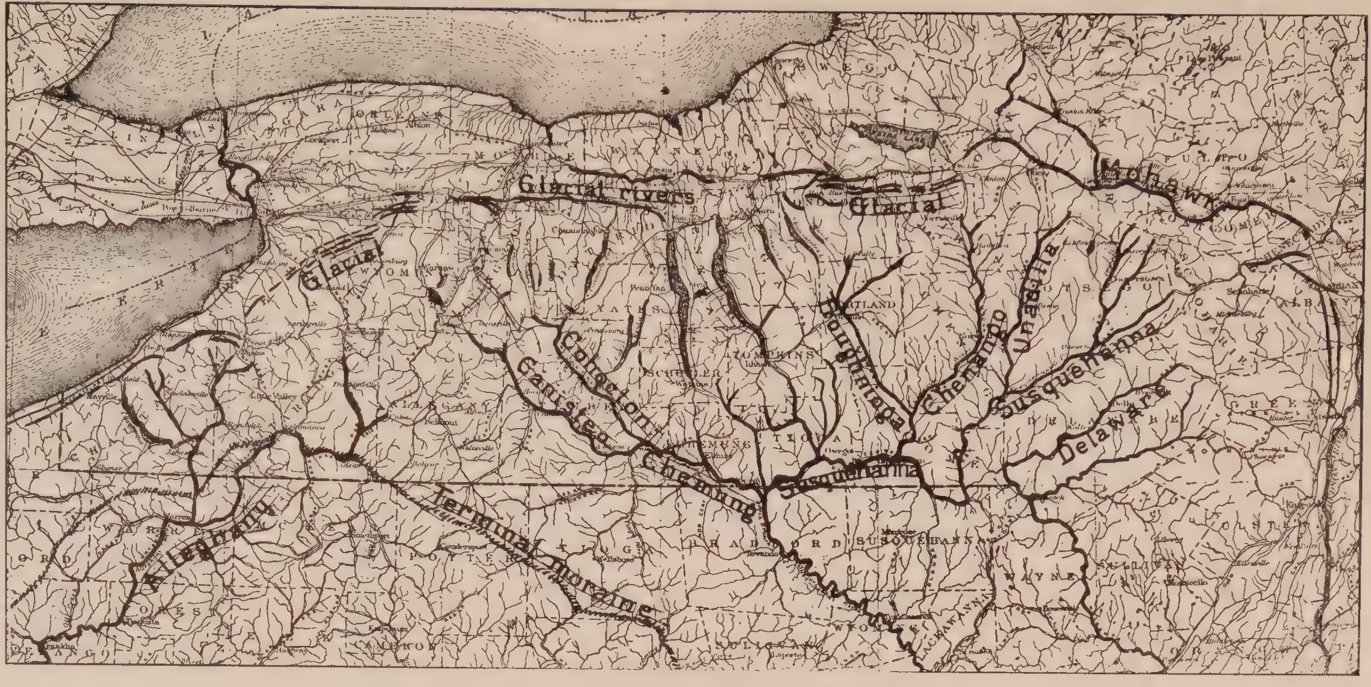
The Ice Invasion; Forced Glacial Drainage

The effects produced by the oncoming ice sheet are a matter of inference. We are sure that the blocking of the drainage must have been in succession, or in order of time the reverse of the same effect during the melting of the ice body and the northward sweep of its southern margin. The changes in the drainage during the waning of the glacier are subjects of observation, and have been depicted in papers 33 (plates 34–42); 34 (plates 2–17); 42 (plates 1–8). The best that could now be done would be to reproduce the serial maps in reverse order. Two of them are reproduced here as plates 7 and 8.

The principal lines of glacial drainage are shown in plate 6. It may be seen that some of these streams do not appear in plate 5, because they were not existing, at least in their present form, in Tertiary time.

Besides forcing all waters into southward flow the ice sheet rubbed its rock-rubbish into the valleys, especially those which were transverse to the glacier movement, and dumped its marginal

Plate 6



MAIN LINES OF GLACIAL DRAINAGE

or moraine drift in such volume in many places as to entirely divert the streams. The moraine fillings at the heads of the Finger lakes valleys are good examples.

Beginning at the western end of the State we find that the ice-impounded waters which were forced across the divide between Mayville and Gowanda were gathered into the Conewango, which, with the morainal blocking, has dismembered the Tertiary Alleghany river. The area of the upper Cattaraugus was drained south by the Ischua creek, which with Oil creek is mapped as forming the Olean creek. The Canisteo and Cohocton rivers are new streams, uniting with the Tioga river from the south to make the large Chemung river. The short, but important, Horseheads river, the outlet of the glacial Lake Newberry (28) is indicated. The Cayuta creek, joining the Susquehanna river at Waverly, is another new stream. The Spencer and the Willseyville creeks, forming the Catatonk creek, carried the glacial overflow of the Cayuga valley. The Tioughnioga river is another new channel, which carried the forced waters of the Skaneateles-Cazenovia district. The Chenango river and the upper branches of the Susquehanna river, having southward courses, naturally carried the glacial flow.

The Genesee valley will be noted in the chapter describing the ice retreat.

The lowest southward escape for the glacial waters of the Finger lakes region was by the reversed Seneca-Susquehanna at Horseheads-Elmira. This flow was the longest in life and largest in volume of any southward flow, but was surpassed by the Iromohawk, leading east from Rome to the Hudson estuary.

The advancing glacier greatly augmented the flow of the Susquehanna, especially in Pennsylvania, not only by forcing the waters of other river systems into tributary connection but by the copious addition of the water produced by the melting of the glacier itself, both in advance and removal.

Extent of the Glacier; Terminal Moraine

By its growth in storing the snowfall of the northland the Quebec glacier eventually reached New York and buried all the State, except a small area at Olean and Salamanca. The slow, unsteady but irresistible invasion by the ice sheet covered an unknown space of time, estimated as at least scores of thousands of years; perhaps 100,000 years. The thickness or depth of the ice increased from a few hundred feet at the margin to many thousand feet in the north part of the State. The plucking, grinding and transporting power of the glacier were proportionate to its weight and pressure and somewhat inversely as its rate of motion. This geologic work of the glacier is principally shown in the masses of rock-rubbish (glacial "drift" or "moraine") dropped along the lines where the oscillating margin lingered in its retreat.

The maximum reach of the glacier across New Jersey, Pennsylvania and New York has been depicted in many publications, and is shown in plate 8, New York State Museum Bulletin 160 (34). The border of the ice sheet is represented in all those maps as a quite continuous or direct line, paying slight attention to the deep valleys or the mountain ridges across which the ice front rested. This is certainly an error, due to following the original maps of the "terminal moraine" of Lewis and Wright.[1] Those early explorers did not sufficiently recognize the lobations of the ice front which occupied the valleys. The glacier was a plastic body which conformed to the topography of the ground surface. Recent study has shown that the ice lobes pushed far forward in the valleys and left masses of drift miles in advance of the supposed "terminal moraine." In the country of high relief the ice margin was a very indefinite and ragged belt. The writer now agrees, from some study on the ground, with the contention of E. H. Williams, to the effect that the supposed pre-Wisconsin drift in the region of Bethlehem, Pa., is only the most advanced deposit of one ice sheet. The entire belt of the terminal drift requires careful revision. In plate 6 the Lewis and Wright line of terminal moraine is partially shown.

The Ice Removal; Recurrence of Glacial Drainage

Now we are not depending on theory but on facts of observation. At its greatest reach the continental glacier reduced New York to the condition of Greenland at the present time. How long the State remained in that condition of cold storage is not known, but probably scores of thousands of years. Eventually the climatic processes which had very slightly lowered the world temperature so as to change the precipitation over Quebec from rain to snow were checked, and finally reversed. The ice body slowly melted, chiefly at its margin. It had expanded when the snowfall exceeded the melting. It diminished when the spreading motion could not equal or compensate for the melting.

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[1] Report Z, Second Geological Survey of Pennsylvania.

During the farthest reach of the ice sheet the north branch of the Susquehanna was reduced to a small stream of the glacial outflow, heading below Berwick, Pa., and having a length to Northumberland of about 30 miles. Not until the ice front had backed away to north of Waverly did New York have any renewed Susquehanna. As the ice front gave place, by northward recession, the river and its tributaries extended their headward growth, as glacier drainage.

The land drainage was, of course, restored as the ice sheet removed, but with such changes as the drift barriers compelled. The forced drainage of the ice invasion was now repeated in reverse order for the main outlets, but with modifications in minor channels due to the morainal damming. The most conspicuous examples of the latter are seen at the divides south of the Finger lakes (30, plate 3). An excellent example of river diversion and cutting of new channels is seen in the Chemung channel southwest of Elmira (plate 10).

The story of the glacial drainage in New York has been related in former papers (29, 33, 34, 42). The Genesee valley is the best illustration in any single valley of the changes produced by the ice blockade. The history of the valley waters during the ice removal has been imperfectly told (28, 32, 33). Its drainage history is probably the most complex of any valley in the world. During both the advance and waning of the glacier its waters were forced into all the principal lines of outflow for New York waters.

In plate 6 the east and west lines of drainage show the latest ice control in New York, these being subsequent to the full restoration of the Susquehanna system.

Changes in Volume of the Susquehanna River

One of the most interesting and important elements in the history of the Susquehanna river is the extreme variation in its volume of flow, due to glacial interference, and the effect of that on its work of transportation and deposition of detritus.

When the ice margin lay at or south of Waverly the volume of the river was zero for land drainage in New York, but was some unknown amount from the subglacial flow of the melting ice. During the removal of the ice sheet and the retreat of its south front the volume of the river increased, until in extreme summer flood it may have been several times larger than Niagara. Plates 7 and 8 (34, plates 12 and 13) show the magnificent glacial Susquehanna. The reader will note that the river carries all the drainage of western New York from the Batavia meridian on the west to near Albany on the east, and in addition all the land and glacier drainage from the Adirondack area. The river systems that were tributary were most of the Genesee, most of the Oswego, plus the Schoharie and part of the Mohawk, and plus the upper reaches of all the streams radiating from the Adirondack mountains. To this must be added the water from the melting ice sheet, with 500 miles of margin and also the precipitation and the melting from the sector of the dome-shaped ice body which drained toward New York, estimated at about 41,000 square miles.

It is not possible to calculate the actual volume of the glacial flood in the Susquehanna valley because of uncertainty as to the meteorologic and geologic factors involved in the removal of the ice sheet, but it is possible to make some reasonable estimates which will give some conception of the order of magnitude of the enormous glacial flow.

When the glacier was invading New York it was storing all the precipitation on its central area and probably part of the snowfall on its marginal belt. When it was waning it was not only shedding all the precipitation upon its entire area but was also losing its own mass. The summer run-off from the waning ice sheet was the rainfall over its surface, plus the melting winter's snowfall, plus the water from the melting ice body.

Our problem requires several assumptions. The general atmospheric circulation and the cyclonic paths are believed to have been similar to the present time; and the chilling effect of the ice sheet probably intercepted some of the moisture which today is carried farther eastward. Hence we may assume first that the precipitation over southern Canada and New York, during the phase represented in plate 8, was not less than it is today. It may have been larger.

The second assumption has to do with the area and drainage of the glacier. The dome-shaped ice body, with its center probably in southern Quebec, must have shed its water in all radial directions. A sector of the glacier drained southward toward New York and into the grasp of the Susquehanna. The area of this sector is moderately estimated at 41,000 square miles. From about one-half of this sector the water passed through Lake Newberry and the Chemung valley (plates 7 and 8), and from the other half by streams and Lake Herkimer to the river above Owego.

The glacial drainage from the New York area, both the ice-free and ice-covered as shown in plate 8, is calculated (from the maps of the State Conservation Commission [1915]) as derived from 26,433 square miles. Of this area about 19,581 square miles drained into the upper tributaries of the river, including the Chenango; while the water from 6852 square miles reached the river at Owego and Athens (below Waverly).

If to the drainage from the New York area we add the contribution from the ice sheet over Canada and Lake Ontario basin, we find in round numbers 40,000 square miles of glacial precipitation area draining to the river at Binghamton, as compared with only 3930 square miles of the present river drainage; while below Waverly the total glacial contribution from over 67,000 square miles was in the river. The present drainage area carried by the river at Wilkes-Barre is only 9810 square miles. These figures appear in the following table:

TABLE 7

Drainage areas of the Susquehanna river

GAGING POINTS	PRESENT DRAINAGE AREA, IN SQUARE MILES	GLACIAL DRAINAGE FROM NEW YORK TERRITORY, IN SQUARE MILES	GLACIAL DRAINAGE, FROM CANADA, IN SQUARE MILES	TOTAL CONTRIBUTED GLACIAL DRAINAGE, IN SQUARE MILES
Binghamton	3 930	19 581	20 500	40 081
Wilkes-Barre	9 810	26 433	41 000	67 433
Harrisburg	34 030	26 433	41 000	67 433

The third assumption is that the water from the melting glacier was at least equal to the precipitation over the area of glacial drainage. The summer rains helped the solar radiation to liquefy the ice. And the run-off was probably larger than over the Susquehanna area to-day, which is about one-half of the precipitation. On the glacier the water ran off promptly, with small evaporation, and the latter was probably reduced in the cool territory bounding the ice sheet. Moreover, the run-off was concentrated in the warm half of the year. These probable conditions permit the fourth assumption that the total annual run-off from the glacial territory was double the amount per square mile of New York today. It might have been much larger. Furthermore, the run-off was concentrated in one-half the year. This suggests as a fifth assumption the possibility of at least temporary summer glacial flow 4 times the volume per unit area of the present time.

Modifying the later assumptions of great flow we recognize an equalizing factor, some storage by the glacial lakes (plates 7 and 8), through which the glacial run-off had to pass. These lakes were so small compared to the great total areas of the glacial drainage that they may be neglected in the following calculations.

The flow of the Susquehanna river has been gaged at Binghamton, Wilkes-Barre and Harrisburg. Using the data given in the United States Geological Survey Water-Supply Papers we can calculate the river flow, under the above assumptions, using the drainage areas of the preceding table.

Adding to the flow from the drainage areas of the present river the contribution from the glacial areas we find that even on the low basis of the annual mean flow we must for Binghamton multiply the river flow by 11, for Wilkes-Barre by 7.87 and for Harrisburg by 3.8. It is with the flood conditions, however, that we are chiefly concerned, and if we figure according to the fourth assumption that the summer flood of the glacial area was per unit area twice the mean flow of the present river, we have to multiply the present flow at Binghamton by 21, at Wilkes-Barre by 14.74, and at Harrisburg by 6.6. If we use the fifth assumption that the summer flood from the glacial area was per unit area 4 times the present mean flow of the river, we have to use as multipliers, at Binghamton 41, at Wilkes-Barre 28, and at Harrisburg 12. The results are given in the following table.

TABLE 8

Glacial river flow with estimates based on the present mean annual flow

GAGING POINTS	PRESENT MEAN FLOW, IN SECOND-FEET	GLACIAL FLOW BY PROPORTIONATE AREAS		
		Glacial run-off same as present river	Glacial run-off twice the present	Glacial summer run-off 4 times present
Binghamton (record of 1902–04)	8 819	97 009	185 199	361 579
Wilkes-Barre (record of 1900–11)	14 661	115 382	216 103	410 508
Harrisburg (record of 1891–1911)	37 225	141 455	245 685	446 700

The above table makes the glacial flow at Harrisburg, even with the run-off per unit area counted as only twice that of the present mean flow, almost equal to the greatest recorded flow of Niagara (see next table). The figures for a summer flood of 4 times the volume of the present mean river flow are probably nearer the truth, and not excessive for at least occasional limited periods.

Perhaps a better basis of calculation is to take as the unit of flood flow the average of the maximum daily flow of the river for the same series of years, and making the moderate assumption of equal summer flood and run-off from the glacial territory. The multiples for the drainage areas are given in parenthesis. The figures for the Niagara and St Lawrence rivers are given for comparison.

TABLE 9

Glacial river flow with estimates based on the annual maximum daily flow of the present river

GAGING POINTS	ABSOLUTELY RECORDED MAXIMUM DAILY FLOW, IN SECOND-FEET	Average of maximum flow	GLACIAL FLOODS BY PROPORTIONATE AREAS	
			Adding only New York glacial area	Adding total glacial area
Binghamton	96 250	83 110	498 660 (X 6)	914 210 (X 11)
Wilkes-Barre	217 700	123 808	458 089 (X 3, 7)	974 368 (X 7, 87)
Harrisburg	543 500	277 000	581 700 (X 2, 1)	1 052 600 (X 3, 8)
Niagara river	257 800			
St Lawrence river	268 000			

In the above table Binghamton has a larger glacial flow than Wilkes-Barre, which of course is impossible. The discrepancy is due to the meager data for Binghamton, covering only 3 years, and those evidently of very heavy floods. The fairer calculation for Binghamton will be to use the percentage relation of the average to the absolute in maximum flow of the other two stations, covering 12 and 22 years, which is 54 per cent. This gives Binghamton an average maximum flow of 51,975 second-feet; and glacial flow of 311,850 and 571,735.

It must be understood that the figures in the above tables are intended only to give some idea of the order of magnitude of the glacial flood.

Fortunately we are able to check the above rather crude estimates of flow based on areas by direct calculations on the stream dimensions, as suggested by the valley deposits. In New York the conditions are not favorable for hydraulic estimates. From Waverly to Great Bend the waters were practically lake waters, while two moraine dams between Great Bend and Lanesboro produced slack water in the irregular valley up toward Cooperstown. The dimensions of the prism of stream flow have not been determined anywhere in New York, but in Pennsylvania we find more favorable opportunity.

Below Wilkes-Barre is the flumelike channel extending from West Nanticoke for 12 miles, the Shickshinny canyon—with quite uniform dimensions and slope. The maps and diagrams in the Pennsylvania paper on the Susquehanna (43) show the valley characters and the features of the glacial flood.

Using the Shickshinny topographic sheet, seven cross-sections of the glacial river were measured, giving an average surface width of 2821 feet, a mean bottom width of 2400 feet, an average depth of 45 feet; and a gradient of 0.5 feet per mile. Charles C. Hopkins, civil engineer of Rochester, specializing in hydraulics and sanitation, has kindly made calculation from the above data. Basing his computation on a cross-sectional area of 117,472 square feet, as the average of the seven cross-sections, and using Kutter's formula with n equal to 0.03, and making C (in the general formula Q equals $A.\ C.\ \sqrt{R.\ S.}$) equal to 100,4, in which general formula

Q equals the flow in feet per second
A equals the cross-sectional area in square feet
R equals the hydraulic mean radius
S equals the sine of the slope

he computes the flow through the Shickshinny gorge as 787,000 second-feet.

Comparing this figure with the estimates for Wilkes-Barre in tables 8 and 9 it will be seen that they are consistent and reasonable.

It is apparent that we are considering a river subject under unusual conditions to remarkable floods, with high gradient, and having very great power. The high sand plains in the river valley, even in the lower part where no damming appears possible, require flood sufficient to give very great depth of water.

When the ice sheet was invading New York the glacial flooding began rather suddenly, and the volume declined as the growing glacier reached southward, until the river was extinguished to below Berwick, Pa. When the ice front receded, the floods increased in volume, the work being largely transportation, with deposition in sections of diminished velocity; and the maximum flow was the latest.

Another factor is important in relation to the height of the floods. During the moderate flow of the ice removal the river was heavily loaded with coarse detritus, and deeply aggraded its channel. When the heavier floods of the closing glacial phase poured down the filled valley, they rode at levels far above the present valley bottoms; and the narrow rock passes at Harrisburg and Columbia were partial barriers and helped to lift the water levels.

It must be emphasized that the enormous volume of the glacial river was repeated, occurring when the glacier invaded New York and again when it passed off the State. The effects or geologic work of the two floods, however, were unlike. It is probable that at the time of the ice invasion the continent stood higher than today, which gave a steeper river gradient. This increased the river's power of erosion, especially in the first great flood when armed with the detritus contributed by the advancing glacier. The drilling effect on the rock bed of the river may account for the peculiar "deeps" in the channel below Columbia, described by E. B. Mathews,[1] and the large depressions in the old channel in the Wilkes-Barre district, described by William Griffith.[2] For further discussion see paper 43.

The great weight of the Quebec ice body evidently depressed the glaciated area, and when the ice sheet melted away the land was much lower than it is today, as described in the next chapter. The effect of the diminished gradient, added to that of the drift barriers in the valley, produced drift-barrier lakes and sluggish flow the entire length of the river from below Wilkes-Barre to the headwaters; and also in the tributaries. In consequence the river in many stretches was depositing sand or gravel, or aggrading its valley.

Changes in Land Elevation

That the glaciated area of northeast America was below its present level when the ice sheet melted away is a fact of observation. The evidence is found in uplifted marine fossiliferous deposits and sea beaches, in the high deltas of rivers flowing to the sea, and in the raised and tilted shore lines of the glacial lakes. The amount of the depression and the oceanic submergence was greater than has usually been estimated, and much more than is commonly suggested by the stronger and more easily recognized phenomena. This subject is treated in former writings (36–39, 42) and the included maps (figures 1 and 2) are the results of long and wide observation.

It is probable that the postglacial uplift, which is measured by the depth of land submergence in the sea when the glacier was disappearing, does not represent the full amount of the downthrow, and that at the beginning of the Pleistocene time the area stood

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[1] Submerged Deeps in the Susquehanna River. Bulletin Geological Society of America, Volume 28, 1917, pages 335–46.

[2] An Investigation of the Buried Valley of Wyoming. Wyoming Historical and Geological Society, Proceedings, Volume 6, 1901, pages 27–36.

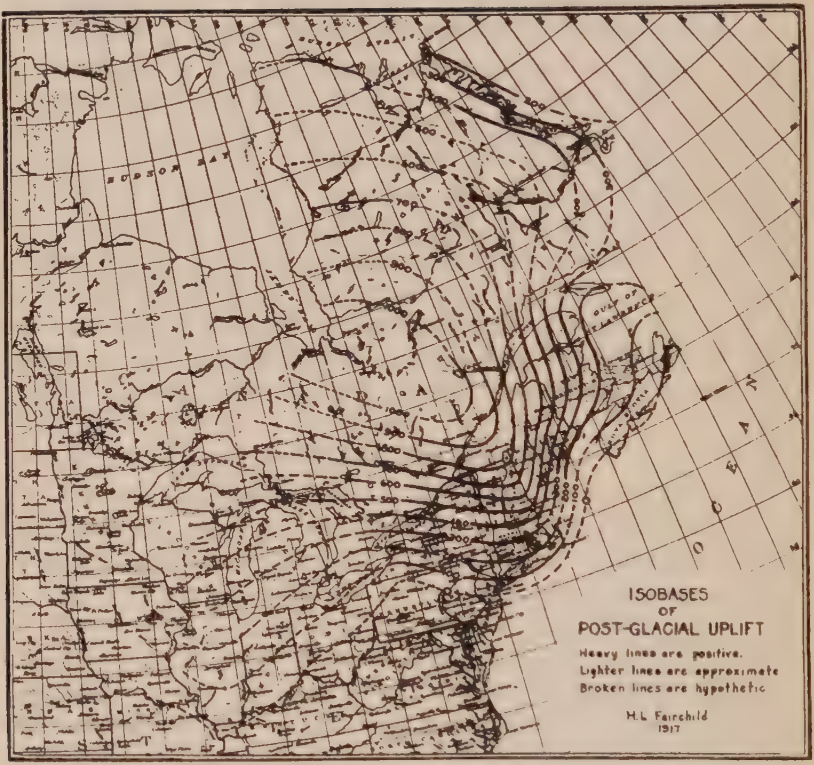

Figure 1 Postglacial Uplift of Northeastern America

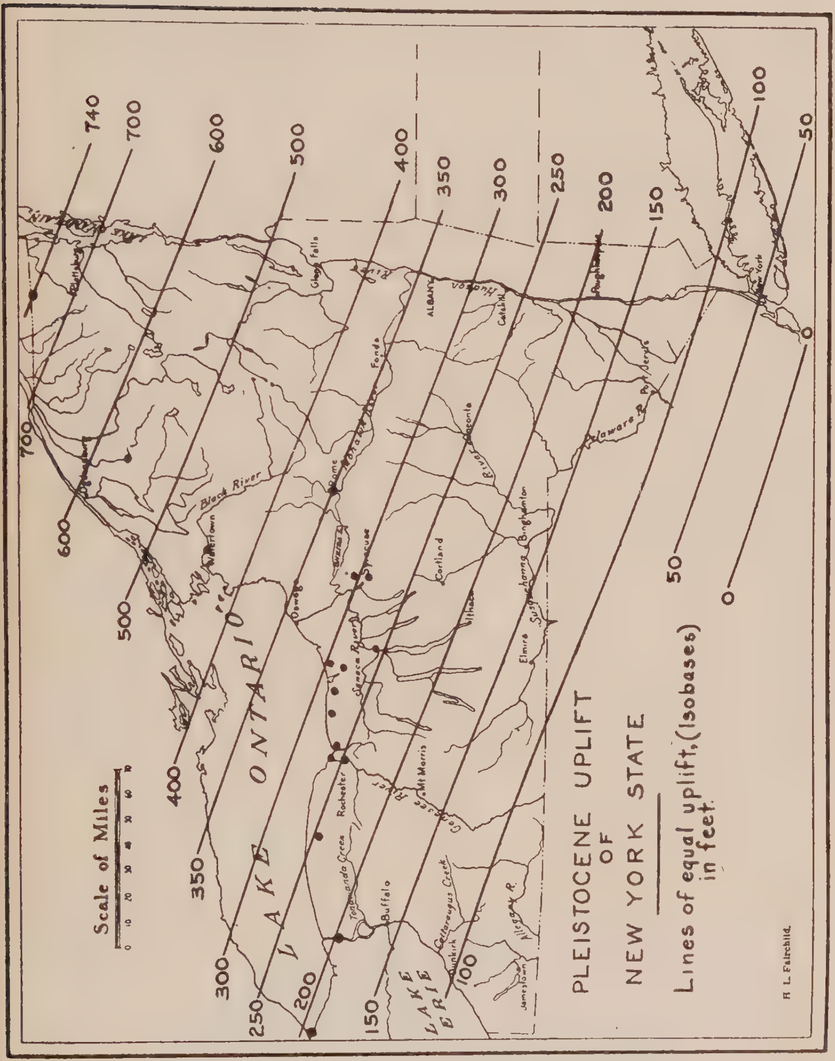

FIGURE 2 ISOBASES OF THE POSTGLACIAL UPLIFT OF NEW YORK

much higher than it is today. It is supposed that the excessive weight of the ice cap, continuous for certainly scores of thousands of years, and perhaps a few hundreds of thousands, depressed the earth's rind, beneath the ice-covered territory, and that the elastic reaction or upward expansion has been only some fraction of the previous depression. The subject is a difficult problem in geophysics and awaits mathematical study.

The lower altitude of northeastern America at the time when the ice sheet melted, and the subsequent tilting uplift, are very important in this study because they help to explain the low gradient and sluggish flow of the south-leading streams with their extensive valley deposits.

In any study or use of ancient water levels in northeastern America it is necessary to take into the account the tilted uplift of the land on all sides of the upraised and dome-shaped area, and also the direction of steepest tilting. In New York the tilt or up-slant is about 2.5 feet a mile, in direction 20 degrees east of north (figure 2).

Some apparent discrepancies found in the heights of the water planes, as registered in the valley deposits, find explanation in this land deformation. For example, the deltas and shore lines in the northern part of Binghamton have elevation of 940–5 feet; but when we go up the Susquehanna valley to Great Bend we find the summit of standing water at only about 915 feet. One would expect river planes to rise up stream, or lake planes to remain level. The maps show that Great Bend lies some 10 miles south of the isobase of Binghamton, and therefore the originally level plains are properly 25 feet lower.

Drift Barriers and High-level Waters

Not only the main valley of the Susquehanna river but the branches also hold vast deposits of sand and gravel which today are merely remnants of extensive stream and lake fillings at high water levels. In New York three causes are recognized for the elevated waters: (1) the immense volume of the river in the early and closing episodes of glaciation; (2) the lower altitude of the land and the diminished gradient of the streams; and (3) the barriers of glacial and stream drift. In Pennsylvania we find a fourth cause, in the several narrow rock passes where the river breaches the mountain ridges. The first two factors have been considered and the others must be described.

The barriers left in the valleys were of two types: those truly glacial or morainic, built in contact with the ice margin, and those piled by the stream itself. The northward recession of the ice border was not only slow but spasmodic, probably by oscillations or retreats and readvances. The more massive deposits, the moraines, were built by the valley ice lobes at their readvanced positions, and in some places these were sufficiently massive to serve as temporary dams to the subsequent river flow. The evidence of such dams is scanty because the tremendous volume of the river in its latest glacial phase and with its continuous normal flow ever since, has swept out most of the dams, or made them doubtful. Two moraine dams have been found, both of them in the big bend of the river between Lanesboro and Great Bend villages.

The water flowing from the melting glacier was heavily loaded with rock stuff (rock-flour, sand, gravel, cobble, bowlders). Where this detritus was spilled into lakes, or standing water, it was piled as mounds or knolls (kames or kame-moraine). Kames are essentially morainal, being frontal or peripheral deposits at the ice margin, which in the present case are the ends of the valley lobations. A large part of the glacial valley deposits will classify as kame.

When the glacial outwash was concentrated in streams of rapid flow the detrital burden was swept down stream. These streams were usually full-loaded with detritus, and aggraded or built up their beds so as to give the necessary gradient for pushing along the coarser stuff. Remnants of the valley fillings, so-called "valley-train," appear in the south-leading valleys of high gradient as the high-level benches and terraces along the valley sides, although more or less mingled and confused with the deltas of the tributary streams. Such combined deposits are more in evidence at, or just below, the junction of the tributaries. Examples will be given below, in the areal description.

In the terminal moraine belt in Pennsylvania such volume of rock-rubbish was piled in the Susquehanna valley, by the combined work of the ice and water that the river channel was deeply filled for a long distance, and the waters of the Wilkes-Barre region were lifted to high level. This most effective and important of the drift barriers was in the canyon section of the valley, extending from West Nanticoke to below Shickshinny. This dam held a large lake in the Wyoming-Lackawanna basin, named here the Wilkes-Barre-Scranton lake. This lake and the depressed altitude of the land in northern Pennsylvania and New York, with some help from drift barriers, produced high-level and slack waters in the entire system of the Susquehanna above Pittston. The features in Pennsylvania are described in paper 43.

The most extensive body of quiet water in New York lay in the stretch of broad valley between Corning and Great Bend, Pa., now named the Elmira and Binghamton lakes. As this stretch has east and west direction, and therefore has suffered small tilting, the fact of horizontality of the water and the detrital plains is more evident.

The lake at Lanesboro, held up by the moraine dams at Susquehanna village and above Great Bend, served as the base level for the water of the upper river, and with the probable help of other barriers up the valley the waters were held much above the present river channel in all the branches, even to the Mohawk divide. The same is true of the Chenango valley, the flow being graded to the Binghamton lake.

On first thought the above facts are surprising and puzzling. The southern part of the river valley in Pennsylvania, including the moraine belt and the principal drift barrier, was deserted by the waning glacier thousands of years before the ice was removed from New York, and it might be supposed that the southern barrier would have been all swept away long before the ice front receded to New York. But there are some complicating factors. One is the long persistence of the Nanticoke-Berwick dam. Erosion of this great barrier must have begun as soon as the ice front lay on the Wilkes-Barre-Scranton lake, for the latter was a catchment basin for the drift above. The Nanticoke filling, however, was some 20 miles in length, while the valley waters were high all the way to Columbia. The drift dam could not be eroded locally or in sections but had to be lowered throughout its entire length. The detritus removed from the upper end of the dam was added down stream. It was tedious work, for the drift was largely coarse material, including multitudes of huge bowlders, and these had to be tumbled the whole length of the river into Chesapeake bay. Second, during all the time of the northward retreat of the ice front the glacial outwash continued to load the streams with coarse detritus and the energy of the river was chiefly used in transportation of the new stuff rather than in erosion of the old. For much of the time that the ice lay on the river, deposition was opposing erosion, especially in the stretches of lower velocity. The third factor is the depressed altitude of New York. The land uplift appears to have been a progressive wave movement, from south to north, following the reced-

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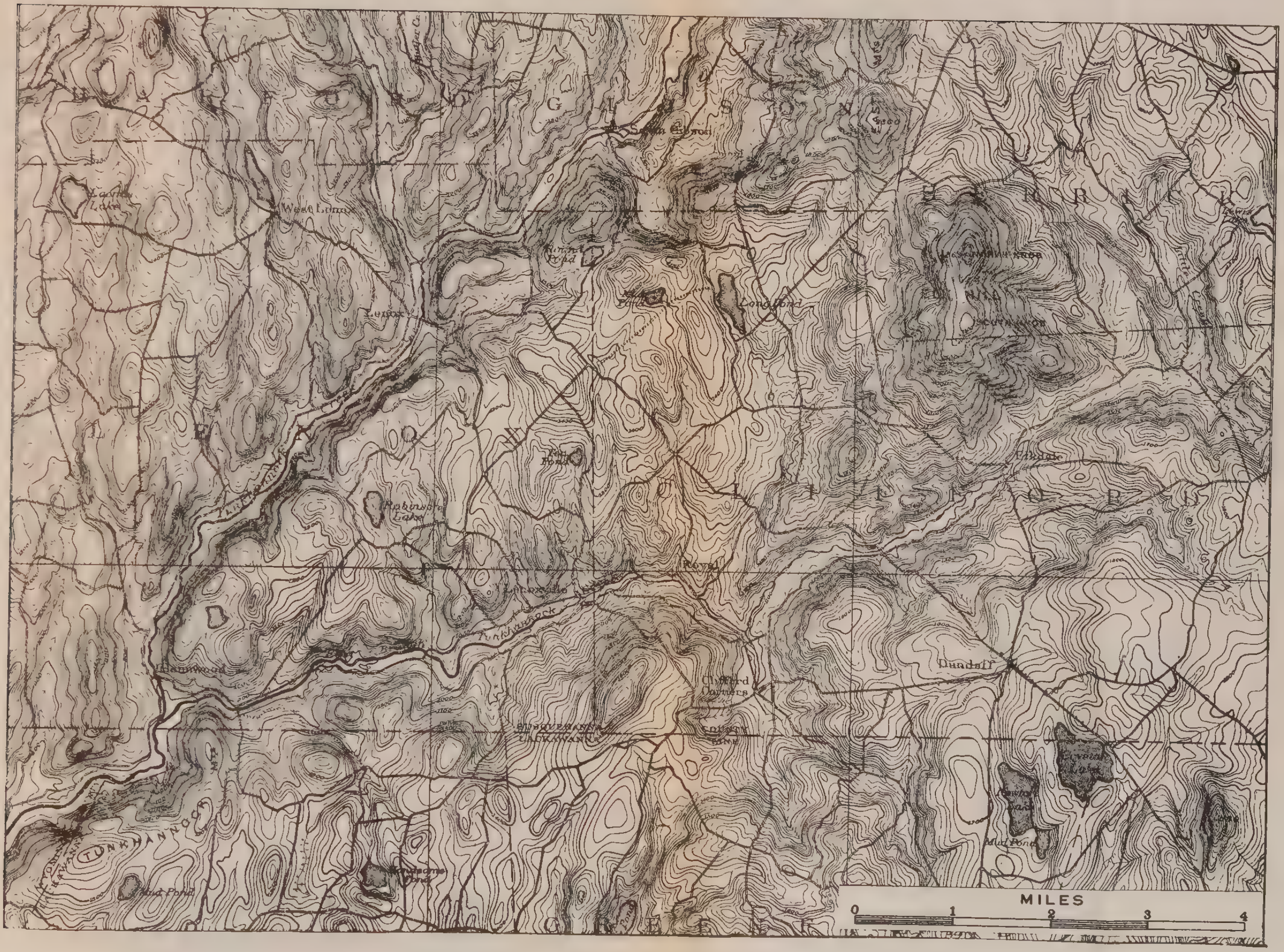
BULLETIN 256 PLATE 9



Elk Hills, in Northeastern Pennsylvania

ing ice margin and relief of weight. It is probable that some, or most, of the rise of land in Pennsylvania took place while New York was yet low. While the effect of this would be to quicken stream flow and increase erosion in the rising area, it would diminish the stream gradient northward, reduce velocity and encourage deposition instead of erosion. The fourth point has to do with the closing flood. The latest glacial flow was the greatest, as shown in plate 8, and until the ice front had passed across the Mohawk divide; at Springfield and East Springfield (plate 21), it was contributing detritus to the headquarters of all the tributary streams. Consequently, up to near the end of the glacial flow the river was perhaps aggrading instead of eroding throughout its length in New York. A fifth factor is the lower power of the normal river, especially in New York. With the opening of the lower Mohawk valley for the escape of the glacial waters (34, plate 14) the Susquehanna was suddenly reduced to its present volume. Then for the first time since its preglacial days its work became wholly erosional. The relatively small volume, however, had a very long and wearisome task in clearing a graded channel through the coarse drift in the long stretch from Cooperstown to Waverly; and that work is not completed, for the river seldom touches rock but is flowing on the deep drift in its old and yet buried valley. The reader will now appreciate the complexity of these geologic problems.

Tilted Water Planes and Valley Gradients

In the figures 4–9 in the following pages the uptilted water levels are somewhat arbitrarily represented by straight lines, drawn through the more definite or better attested points of elevation, the line being intended to serve as a datum line, and to give suggestion of the approximate elevation in all localities. Measured elevations are indicated by an arrow point (/\), with the altitude given in feet above tide. In many localities the map contours show plains which agree closely with the datum lines.

The steep slope shown in the diagrams (figures 5–9) is partly due to the postglacial differential uplift of the land. Even when this is deducted there still remains, however, in many valleys a considerable total fall, which in some valleys, like the upper Susquehanna and the Chenango, may be partly explained by local drift dams and successive pondings of the valley waters and partly by the closing glacial flood. A much greater tilting of the land does not appear admissible.

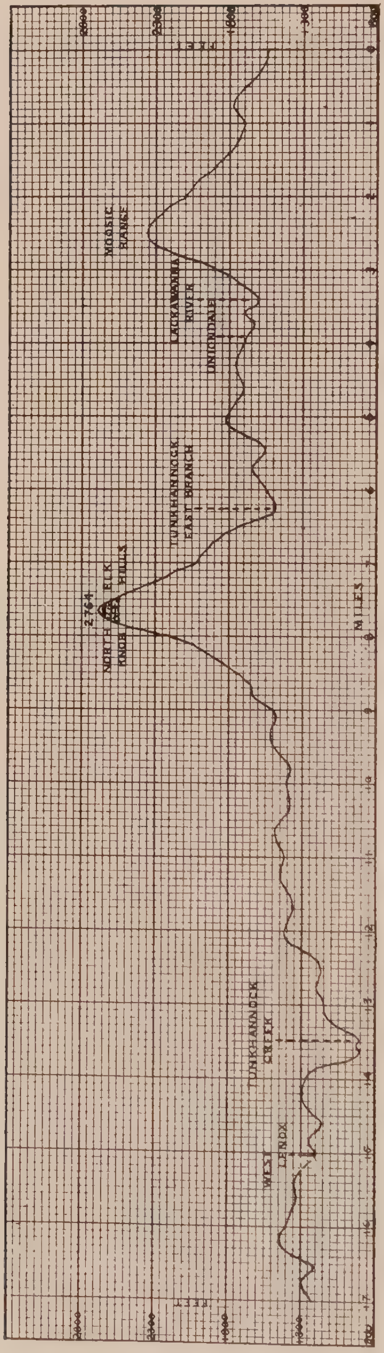


FIGURE 3 PROFILE, EAST AND WEST, ACROSS THE ELK HILLS OF NORTHEASTERN PENNSYLVANIA

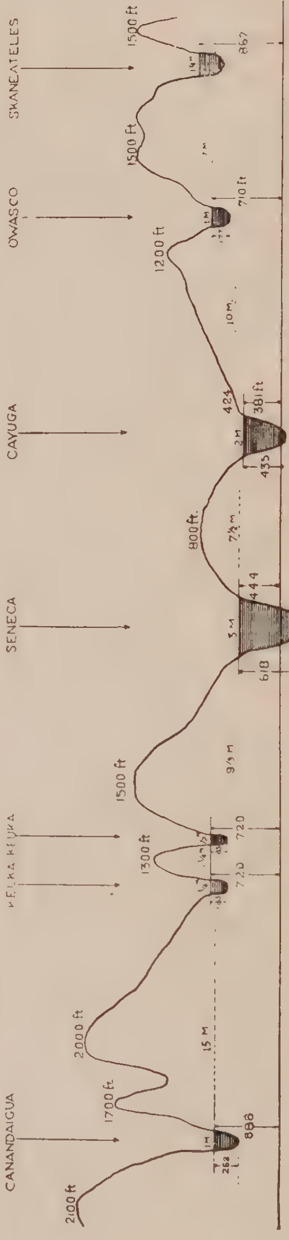


FIGURE 4 PROFILE EAST AND WEST, ACROSS FINGER LAKES VALLEYS SHOWING DEPTH AND GREATEST WIDTH OF LAKES. BASE LINE IS SEA LEVEL

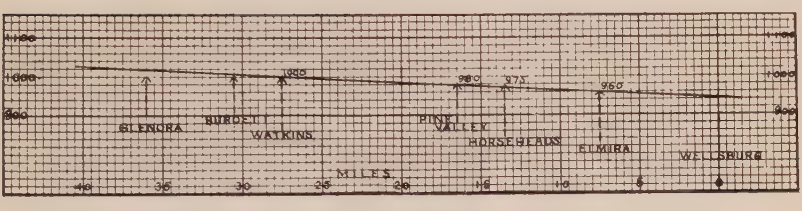


FIGURE 5 PROFILE, ELMIRA LAKE PLANE; WAVERLY TO GLENORA

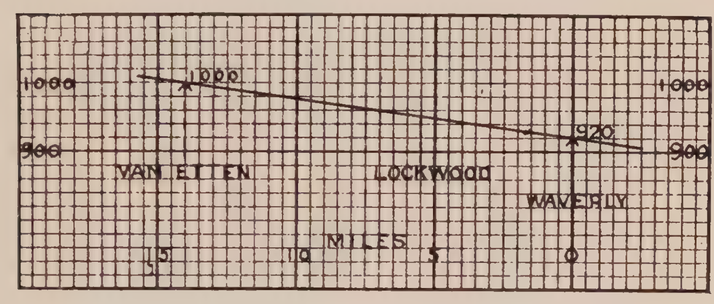


FIGURE 6 PLANE OF CAYUTA VALLEY WATERS; WAVERLY TO VAN ETTEN

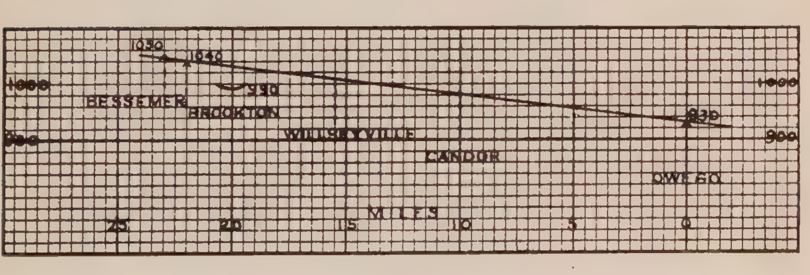


FIGURE 7 PLANE OF CATTATONK VALLEY WATERS; OWEGO TO ITHACA

The following table includes the data of the diagrams (figures 5–10) and the valley east and west of Waverly (*A* and *B*).

TABLE 10

Altitudes and gradients (in feet)

EXAMPLES	VALLEYS AND ELEVATIONS	PRESENT RISE OF PLAINS	DIFFERENTIAL LAND UPLIFT	ORIGINAL RISE OF WATER SURFACE	DISTANCE IN MILES	ORIGINAL GRADIENT PER MILE
A	SUSQUEHANNA Waverly, 920 feet Binghamton, 945	25	30	—5	41	0
B	CHEMUNG Waverly, 920 Elmira, 960	40	5	35	18	2
5	SENECA Elmira, 960 Watkins, 1000	40	35	5	21	0
6	CAYUTA Waverly, 920 Van Etten, 1000	80	25	55	14	4
7	CATATONK Owego, 930 Brookton, 1020	90	30	60	22	3
8	SUSQUEHANNA Lanesboro, 1004 Cooperstown, 1250	246	140	106	80	1.3
9	CHENANGO Binghamton, 945 Bouckville, 1200	260	130	130	69	1.9
10	COHOCTON Corning, 960 Cohocton, 1310	350	35	315	35	9

It should be recognized that we are dealing with variable factors: inconstant water levels and deltas and sand plains with uncertain relation to the water surface. Precision is usually impossible, and some variation in vertical range must be allowed. For example, the figures for A of the table give a minus amount for the Waverly-Binghamton water plane. There are three sources of this small discrepancy: the level at Waverly may be taken a little too high, or the Binghamton one too low, or the land uplift may be given too high; or all three elements may be compromised. But the difference of 5 feet in 41 miles, considering the variables, is reasonable proof of original horizontality. In example 5 we have an opposite variation of 5 feet.

In the remaining cases the variation from original horizontality is too large to permit of continuous lake level; but in examples B, 7, 8 and 9 the explanation appears to be a series of lakes, or slack water, due to local drift barriers or to a glacial river of great volume. In examples 6 and 10 it is clear that we have only stream conditions.

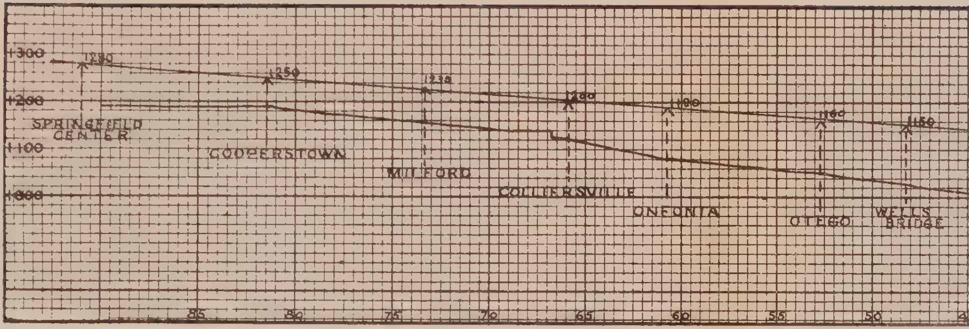


FIGURE 8 PLANE OF THE SUSQUEHANNA V

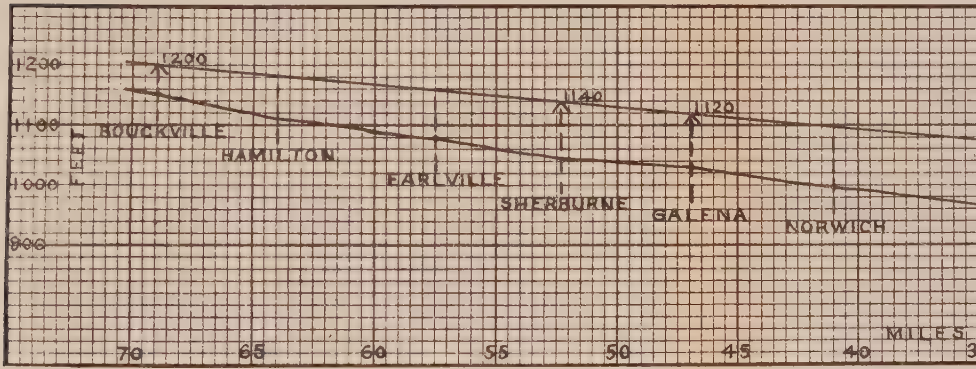
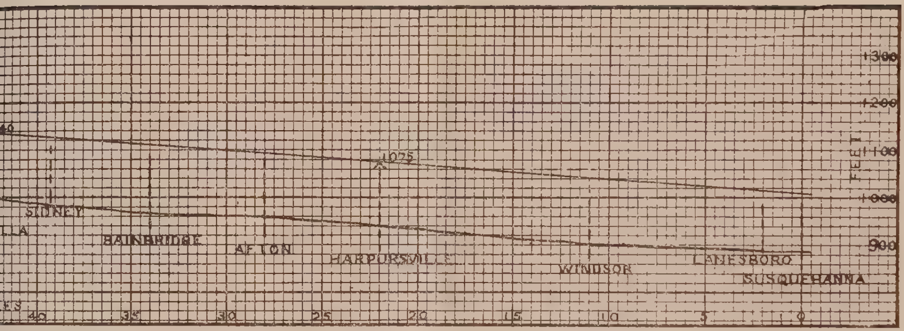
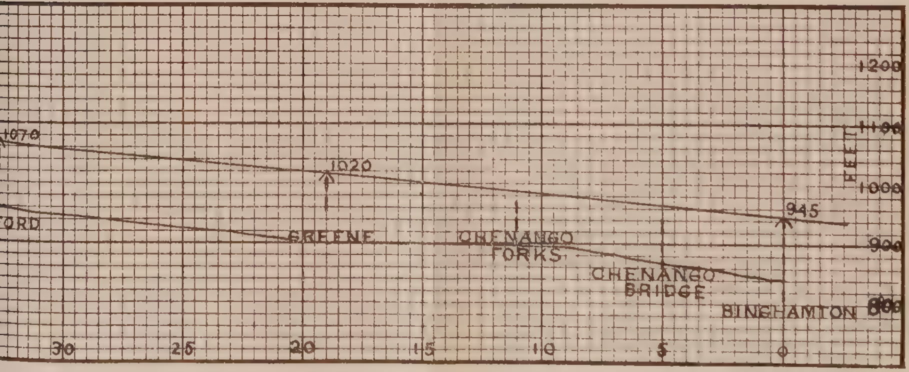


FIGURE 9 PLANE OF THE CHENANGO



y Waters; Lanesboro to Cooperstown



ey Waters; Binghampton to Bouckville

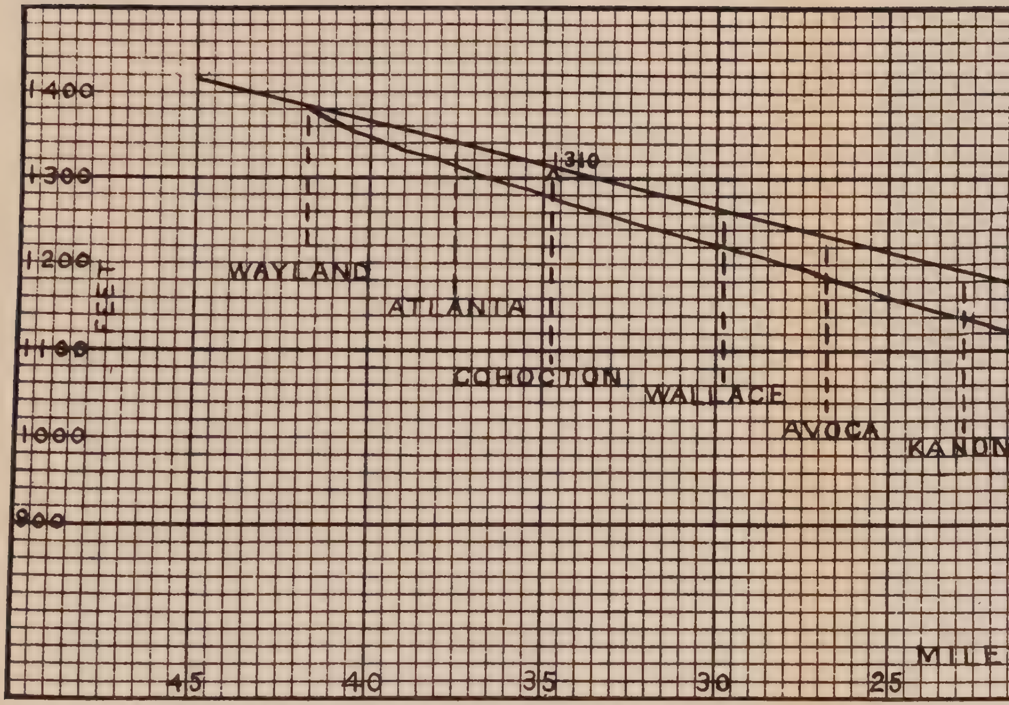
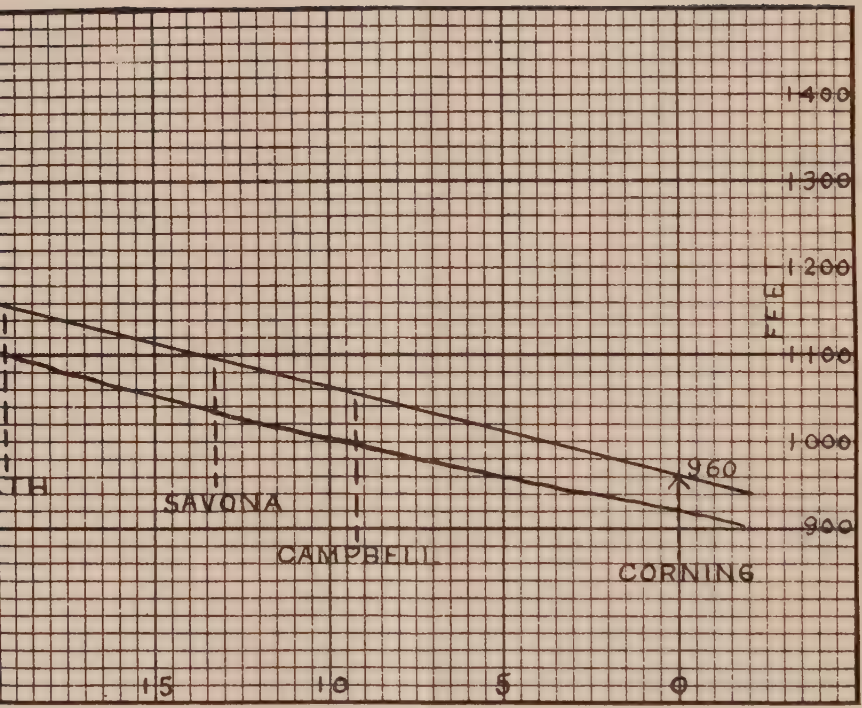


Figure 10 Plane of the Cohocton Gl



River; Corning to Wayland

DESCRIPTION OF THE VALLEY FEATURES

Classes and Forms of the Deposits

In the hope of making this writing of scientific interest and educational value to the people residing in the valley of the Susquehanna and its tributaries the following description is given with some detail and particularity for the several localities. The description will relate chiefly to areas adjacent to the cities and larger villages, where the descriptions may be readily verified and new observations made by the instructors and pupils of the colleges and high schools. No locality is fully described, as it will be more interesting and stimulating to the reader and student if he can make some discoveries of his own.

Some knowledge of the rudiments of geology and physiography on the part of the student must be assumed, but the following brief discussion of the origin and character of the valley deposits may be helpful.

Rounded rock materials, grading in size from bowlders down through gravel and sand to silt and clay, and lying with the assorted sizes more or less stratified, must always be recognized as the work of water. The coarseness or size of the particles is directly proportionate to the velocity of the water, from which it follows that silt or clay implies quiet or slack water, and fine sand requires very gentle flow. Every observant person familiar with the river valleys must have recognized such water-laid deposits along the valley sides, and high above any possible reach of present-day floods. The ancient deposits of sand and gravel usually form level stretches, as plains and terraces, and are conclusive proof of either stream or lake at the height of the deposit. The study of these deposits in their geologic and time relations is not surpassed in disciplinary and cultural value by anything taught in the schools.

In many localities, especially on the higher ground or above the reach of the higher valley waters, but sometimes in the valley and more or less buried in the river deposits, the glacier has left deposits of ice-laid materials, which should be discriminated from the water-laid. The latter are stratified and in assorted sizes. The former are unassorted stuff of all sizes, shapes and kinds of material, usually containing rocks from regions far northward, even crystallines from Canada or the Adirondacks. When this glacial-drift, or till or bowlder-clay, is heaped in irregular masses, hills or knolls, it constitutes a moraine, and represents at least a relative standstill of the receding ice margin, and should be carefully mapped.

The water-laid deposits, the sand and gravel, will also contain all kinds of harder rock, the same as the till, because much of the river-borne drift was contributed by the glacier which gathered some of it in the far north. Discrimination from ice-laid deposits relies on structure and not on composition.

The water-laid valley deposits fall into several groups, according to their origin and relation, and the recognition of the different kinds in field study will be found interesting, and commonly not difficult.

1 **Kame and kame-moraine.** These are knolls or mounds, small or large, built by streams pouring out of the ice sheet into quiet water. The materials are poorly assorted, with obscure or irregular bedding at variable inclinations. Kames are of the nature of incipient, short-lived deltas. They are often associated with eskers, the latter being coarse deposits in the beds of the subglacial streams which fed the kames. Kames are essentially morainal, belonging to the frontal deposits of the ice sheet.

2 **Eskers.** As above noted, these are the singular, sinuous and steep-sided ridges of coarse gravel or cobble, usually lying along the bottoms of valleys. They were built of the laggard materials in streams which were flowing at the bottom of the ice sheet, near its margin, and which were supplied with more coarse detritus than they could carry. The best example seen in the Susquehanna valley lies west of Lanesboro, curving around to Susquehanna village (plate 33). Another of great length lies in the narrow valley of Dudley creek, between East Richford and Center Lisle (Harford sheet), and carries the highway for long distances. Eskers are peculiar phenomena, and before the science of glaciology they were unexplainable.

3 **Delta plains.** When these were laid at the ice front by the outwash of the melting glacier into lake or sea they would normally slope away from the ice front, and the ice-ward margin might blend into the glacial stuff, and it might have the irregular form of the ice contact. When high plains occur at the mouths of tributary valleys they represent the deltas of the side streams, and will naturally grade into the high flood plains of the latter. The surface of large deltas of coarse material may be higher than the water level of the receiving body; but the front of a delta of fine material, as fine sand or silt, was beneath the surface of the standing water.

4 **Lake plains.** These are level stretches of sand and gravel, built usually along the margins of the standing water. The material was contributed from glacial outwash or by contribution from land wash and inflowing streams. They may have different levels, or terraces, if they lie in a lake area of falling water levels. They grade into the flood plains of the river and its tributaries, from which they may not always be distinguished. The present plains are only fragments of the original plains.

5 **Flood plains of the river valley.** These are the more common and conspicuous of the valley features. Along the valley sides they form benches or terraces which represent the slowly falling levels of the river. In areas of lakes, like the Elmira and Binghamton lakes, they include only the lower plains. In a stretch of the valley where the slope of the plains up stream is greater than can be due to the land tilting they must represent the border deposits of the river; the Cohocton, for example.

6 **Flood plains of the side valleys.** The tributary waters were graded to the falling waters in the main valley, except as local lakes were held in by drift dams. In the larger valleys, like the Unadilla, Chenango or Otselic, it is difficult to say if certain higher plains are of lake or stream genesis. In those of very steep grade, like the Cohocton, the plains must be flood plains.

All the conspicuous phenomena of the valleys are related to the waning and removal of the ice sheet. The only deposits which can possibly be attributed to the invading ice, or the time of the oncoming of the glacier, are some of the deepest, hard, blue tills, which are found in some deeply eroded stream channels. It is possible that some of the deeper gravels in the valleys may be related to the outwash of the advancing ice front, but such have not been recognized.

The important and most interesting element in the field study of the water deposits is the determination of the full height or summit level of the lake or slack waters. This is the most difficult, yet on that account the most instructive. As the waters were slowly drained away, the detrital materials were swept down to lower and lower levels, and the later and inferior plains are commonly the more conspicuous. In no one locality should the highest visible plain, taken by itself, be confidently regarded as the summit water level. In many localities the highest plains which appear to mark the highest stand of the water are found to lie below the true summit, as proven by yet higher plains in nearby localities. The summit may be approximately determined by finding the altitudes along considerable stretch of the valleys. Sometimes the little deltas of weak streams, or even wet-weather runs, on the sheltered valley walls, are excellent criterions.

In the following pages the figures given for the higher plains must not be understood as absolute. They are subject to possible correction. The approximate summit water level for any locality may be found from the profiles (figures 5–10).

A very interesting fact is that nearly all the cities and villages in the Susquehanna valley and the larger tributary valleys are built on the old gravel plains. They owe their location and often their expansion to the continental glacier.

It must be recognized that the rock hills and the broad valleys are all preglacial, dating from Tertiary time.

Elmira and Binghamton Lakes

Plates 10–15

Two lakes existed in New York which were rivals of the Wilkes-Barre-Scranton lake in Pennsylvania. These lay in the Susquehanna and Chemung valleys, along the south line of the State.

The Binghamton lake filled the Susquehanna valley from Towanda up to Great Bend, with a short arm up the Chenango valley to Chenango Forks. The cause of this lake must have been moraine barriers in the narrow stretches of the winding valley south of Towanda.

The Elmira lake was held at a somewhat higher level, evidently by drift barriers in the east and west stretch between Waverly and Wellsburg. The standing water extended from Wellsburg to Corning, with a long north branch in the Seneca Valley. At the west end the lake plains grade imperceptibly into the old river flood plains of both the Cohocton and Canisteo valleys.

In the earlier study of the large area it was supposed that a single water body occupied both the Binghamton and the Elmira districts; but close examination of the detrital plains, in their altitude relation to land uplift, requires the separation into two lakes. As the general trend of the lakes was east and west the area was not greatly tilted by the postglacial land uplift, but the deformation was sufficient to clearly show and to be useful in translating the history. For example, on account of their more southerly location the plains at Great Bend are 25 feet lower than the Binghamton plains, but at Elmira and Corning, which are farther south of the Binghamton isobase than Great Bend, the plains are 20 feet higher than at Binghamton (figure 2).

These lakes were too narrow to admit of heavy wave work and production of conspicuous shoreline features, and we have to depend for the elevations of the water surfaces chiefly on the detrital plains and deltas, which are commonly below summit level.

These lakes fell away as the holding barriers were slowly eroded. It is possible that the Binghamton lake was extinguished when the closing glacial flood (plates 7 and 8) swept through all barriers.

Corning District

Corning sheet, plate 23

The western limit of the Elmira lake is found here. The wide plains, at 920–30 feet, which carry the lower part of Corning city and North Corning and Painted Post represent the lower levels of the lake. Above Painted Post up both the Cohocton and Canisteo valleys the plains become the old flood plains of the swollen rivers contemporary with the lake. The rivers have not greatly intrenched the old plains, for the Chemung has elevation of 920 feet at the point of its origin, and 900 feet a mile below Corning. The channels of the Canisteo and Cohocton, cut in their old flood plains, are still quite shallow.

Gravel bars of wave construction must be very rare in the lake area, but the long stretch of open water on the east toward Big Flats permitted wave development and the piling of a gravel bar on the west side of the valley below Corning. This is southwest of the Protestant cemetery, along the west side of the Erie railroad. At the north end of the bar by the corner of the cemetery an old gravel pit shows the nature of the deposit. The bar terminated here in a wave-eroded cliff on the steep hillside. The elevation of the bar is 935 feet. It indicates a fairly steady level of the lake for a time with water 35 feet deep.

Elmira District and Seneca Valley

Elmira, Waverly, Watkins sheets, plate 10

In the Elmira region we have the most extensive plains of the whole drainage area of the Susquehanna, and a complex and interesting history. The wide valley, now deeply filled with detritus, between Big Flats and Horseheads was in preglacial time the course of the Chemung river, while the extensive plains north and south of Elmira and north of Horseheads are filling in the supposed ancient valley of the Susquehanna (plate 5). The narrow valley now occupied by the Chemung river from Big Flats to Elmira is a new course of the river into which it was forced by the ice blockade. It is a fine example of recently diverted river flow. This Elmira sheet is one of the most interesting physiographic maps in the United States.

The new valley of the Chemung, some 7 miles in length, must have been in Tertiary time the valley of one or two small tributaries of the great rivers. During the ice advance the Chemung was compelled to take and deepen this small valley. Then it was overridden by the glacier and partly filled with drift. When the ice front in recession passed over the district the Chemung was compelled to permanently follow this course, but it has not been able to excavate it deeply.

The spread of the Elmira lake is fairly indicated by the white areas of the map, but the plains are inferior to the summit level of the lake. The plains represent a part of the load of detritus swept into the lake, from the west by the glacial Chemung and from the north by the outwash of the ice sheet. The detritus was spread and smoothed by the falling lake waters and by the earliest flow of the rivers. Below Elmira the Chemung is flowing on the lake filling which was recently its flood plains. At Wellsburg the river by the map is 800 feet above tide. South Elmira is on ground at 840–80 feet. Under Elmira the plain rises from 840 to 900 feet, and at this level spreads north to Horseheads and west to beyond Big Flats. The summit level of the early lake is shown by the weak shore line features about the valleys, and especially by the deltas of the smaller streams built in the lake. The west side of the valley at Elmira and north to Horseheads will afford good data. Along the steep valley wall east of the city are conspicuous benches built in the waters by the storm-wash from the high slopes (plate 29). The best locality for study of the sand plains and water level is the extensive plain north of Horseheads and the shore line between the north branch of Newtown creek and Catherine creek, where the combined forces of the streams built a splendid delta plain. At the road corners where Catherine creek debouched into the lake is the north head of the gravel delta, with altitude by the map of about 975 feet. Farther north, at Pine Valley, heavy, conspicuous plains lie on both sides of the valley up to about 980 feet. The tilted water plane falls to about 960 feet at Elmira. The summit level is seen at Woodlawn cemetery and Carrs Corners, where Heller creek and Hoffman brook swept in their detritus. The city is built on inferior plains, the business portion on the abandoned Chemung flood plain at about 840 feet.

Another interesting glacial feature is found in the Elmira district, and shown in plate 10. This is a local glacial lake held in the Newtown valley at Breesport and Erin. The last phase of the glacier in the district was a lobe or tongue of ice lying in the large valley over Pine Valley and Horseheads. This ice lobe closed the Newtown creek valley and the waters ponded in the "Breesport glacial lake" were forced south through Baldwin creek. The head of the outlet channel is a mile and a half south of Breesport, with altitude about 1160 feet. A later and short-life pass seems to have been behind the hill northeast of Horseheads at 1100 feet. Below Breesport the creek has eroded its channel in the lake filling, but this rises to 1260 feet at Erin.

The classes in science of the college and high schools should find instructive and fascinating work in tracing the glacial phenomena, in determining the precise summit lake level and in discovering the details of the glacial history. Many very interesting and curious features may be found. For example, the basins in Eldridge Park are "kettles," produced by the late melting of detached ice blocks which had been buried in the detritus of the plain. Other kettles lie 2 miles north of Horseheads. The most important investigation is the measuring of the depth of drift in the valleys, and discovery of the altitude and form of the preglacial rock valleys.

As the ice lobe melted away it was laved and followed by the highest waters of the Elmira lake, which eventually extended into the Seneca valley for some distance north of Watkins. At Watkins the level of the Elmira lake is seen at the head of the famous glen, by the station of the New York Central railroad, where the delta of Glen creek has an altitude of 1000 feet. Eight miles farther north, and southwest of Glenora, Big stream and Rock stream have combined to build elegant delta plains. The highest terrace is south of a road corner, on land of Willis Barber, with elevation of 1000 feet. The heavy benches below, beginning at about 965 feet and falling to 900 feet belong to the successor to the Elmira waters, Lakes Watkins and Newberry (30, 33). Other yet lower terraces correlate with subsequent lakes, Hall, Vanuxem, Warren and Dana.

On the east side of the valley the village of Burdett stands on delta plains rising to 1000 feet. The village of Odessa, 5 miles southeast of Watkins, is built on broad gravel plains at 1020–50 feet. It will be noted that this level is above the plane of the Elmira waters, while the Burdett and Glenora levels are below. The Odessa gravels were laid in the local "Odessa lake" which was held up by the Seneca valley ice lobe. The higher waters of this Odessa lake found outlet near Alpine to Cayuta creek, at 1160 feet; and the plains at Odessa village must represent escape of the waters along the steep valley wall 3 miles southwest, into the Elmira waters that were displacing the Seneca ice lobe. This relation of ice-dammed waters in embayments on the sides of the larger valley suggests the complexity of the phenomena, and the caution to be observed in study and correlation of the water levels.

We have noted the discrepancy between the levels at Watkins and Glenora. A glance at the profile (figure 5) shows that the Watkins Glen level lies in the plane of the summit levels at Elmira and Pine Valley, but that the Glenora and Burdett terraces are somewhat lower. The explanation illustrates the necessity of knowing the events or steps in the glacial history. During the life of the Elmira lake the drift barriers which were holding up the lake were being lowered, with eventual draining of the lake. It appears that the Seneca valley ice lobe had diminished so as to let the lake waters penetrate alongside the ice tongue as far north as Watkins while the lake retained nearly its summit level, but that by the time the waters had penetrated to Burdett and Glenora the water surface had fallen; and when the lake had lowered to near the valley bottom above Horseheads so as to produce river flow across the deposits in the Pine Valley-Horseheads district a new and distinct series of lakes were held in the Seneca valley. The immediate successor of the Elmira waters in the Seneca valley was Lake Watkins. By further recession of the ice front in central New York Lake Watkins penetrated into the Keuka valley on the west, and into Cayuga valley on the east, and the much expanded waters were named Newberry (28). The later outflow of Newberry cut the definite channel which appears some 2 miles above Horseheads and is followed by Newtown creek to its junction with the Chemung river. In the downcutting through the lake deposits by the Newberry outlet, the Horseheads river, terraces were shaped on either side of the channel. Two benches on the east side below Horseheads are conspicuous (plate 29).

In the earlier papers by the writer the existence of the high waters, Elmira lake, preceding Lake Newberry was not recognized, as the Susquehanna valley history was unknown. In 1903 M. L. Fuller noted the complexity of the features (27); and the Horseheads features were also mentioned by Tarr (15).

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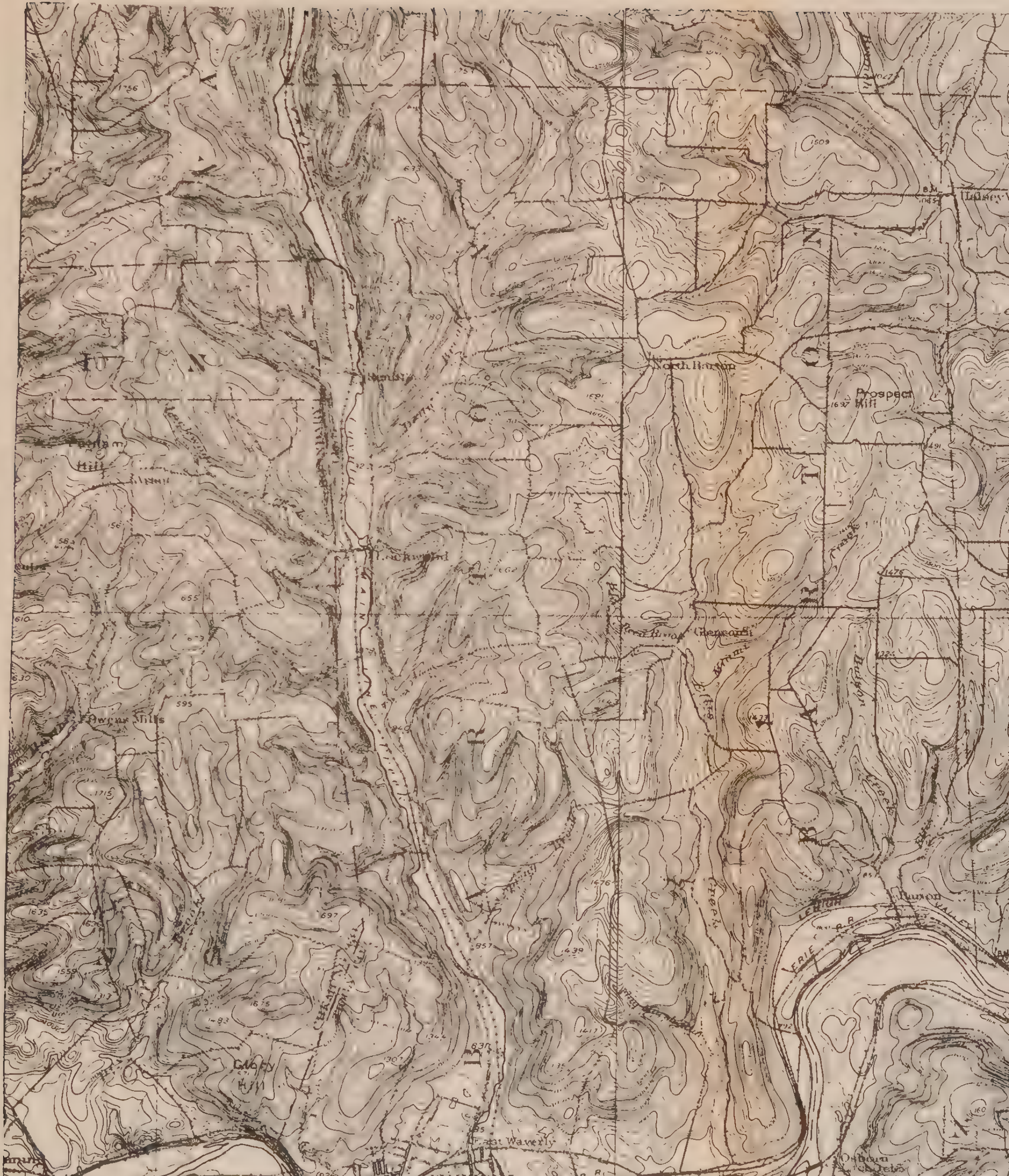

WAVERLY-OWEG

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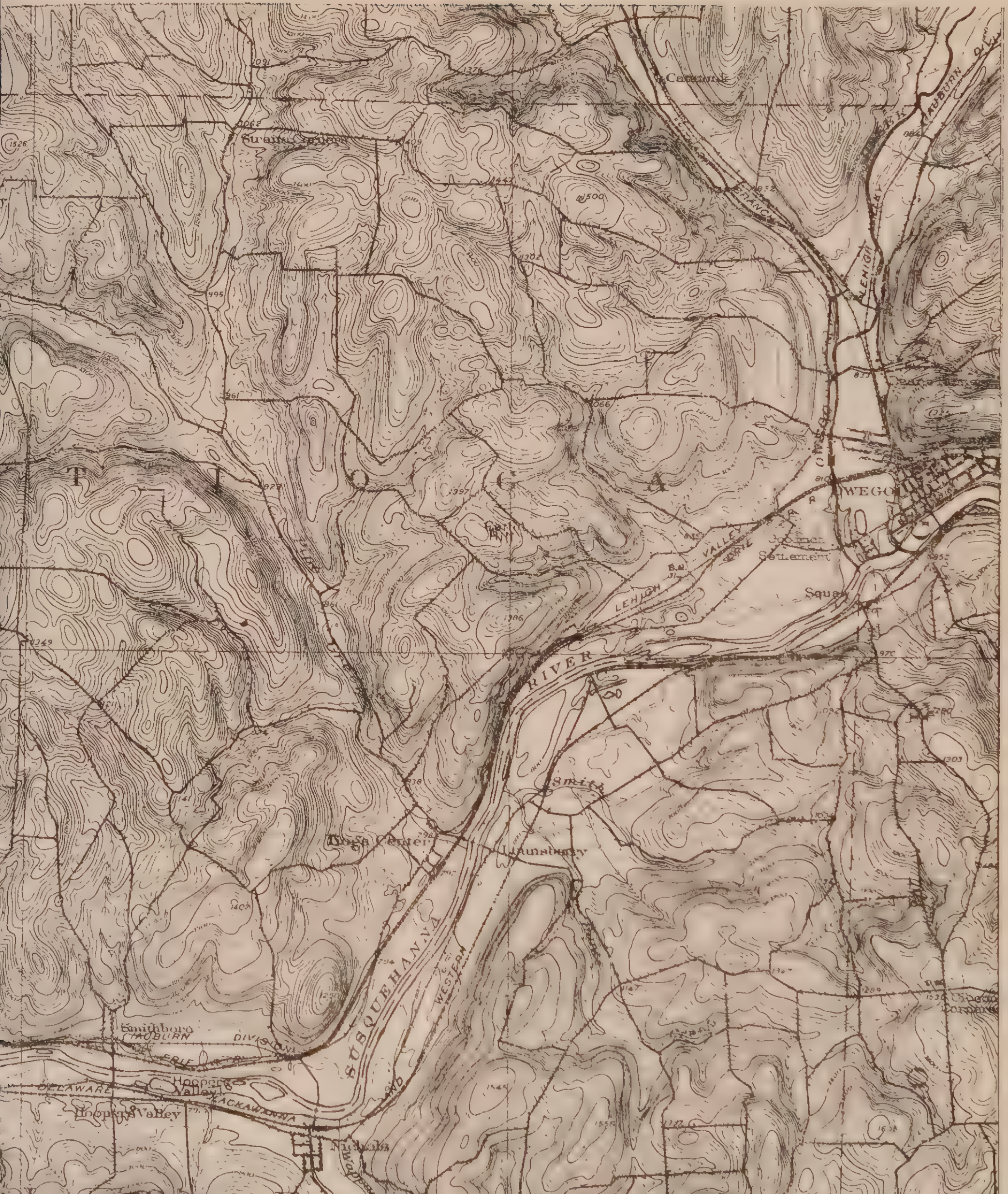
BULLETIN 256 PLATE 11



ISTRICT

Waverly District

Waverly sheet, plate 11

This district is the most critical in the history of the Susquehanna river, but unfortunately the river and nearly all the valley features lie in Pennsylvania, and we have no topographic maps. The villages of Sayre and Athens stand on the extensive low plains that occupy all the space between the Susquehanna and Chemung where they are reluctant to join their waters. Waverly lies mostly in New York, on the higher northern edge of the valley plains, with elevation along the main street of 835 feet, and rising to 900 feet in the north part of the village. At the entrance to the cemetery northwest of the town the delta plain is 920 feet. West of the village and close west of the golf ground a poorly developed gravel bar stands at 910 feet. Northeast of the village the plain carries many kettles; while eastward for 3 miles the valley holds a kame-moraine.

It might be a disappointment not to find a heavy delta here, where Cayuta creek poured a glacial flood into the Binghamton lake. The explanation is that the glacial drainage lodged its detritus farther north, in the Van Etten district (plate 13), and that the lower part of the Cayuta valley was buried in the lake waters. The lake deposits in the narrow valley have nearly all been swept out by the creek, but remnants of the side deltas are seen at Lockwood, Reniff and other points.

Spanish hill, southwest of the village, stands out boldly as an isolated mass, with its summit about 1000 feet elevation. Its surfaces are glacial and lake deposits, and on the north side it carries a kame-moraine of high relief with deep kettles. Until its interior structure is known, whether rock or drift, its significance in reference to the valley history can not be known. If it has a core of rock it is an outlier of Chemung strata, and has been the witness of the shifting and reversal of flow of the great river. It may be well to epitomize the history of this important locality.

It is possible that in early Tertiary time the river flowed south at this point, as today. We do not know. It may be that when the Susquehanna had been brought here the path around to the Seneca valley was more attractive. It is almost certain that it took the Seneca valley course in the late Tertiary period (plate 5). Then it was joined here by a small stream that headed somewhere in the Towanda region. When the implacable ice sheet had conquered New York so as to block the Mohawk valley, the tremendous glacial flood of the Susquehanna and the Chemung united here for the eroding plunge southward. When the ice margin lay at this locality the erosive effects of ice and water combined might have been unusual, but are unknown. Then for tens of thousands of years the deep ice sheet scraped the region, sandpapering the hills and pushing drift into the valleys. When the glacier was overcome by climatic reaction and passed off New York the drama of river and glacier was reenacted in reverse order.

At Sayre the Susquehanna is on rock; but this is on the east edge of the great valley, and so has little value as to the depth and location of the Tertiary drainage. All possible data with reference to the depth of drift, or rock altitude, in the valleys should be collected if we are to know the true river history. When the Sayre and Towanda topographic sheets are published it may be possible to add some interesting elements to this sketch of the important district.

Owego District

Owego and Apalachin sheets, plates 11 and 12

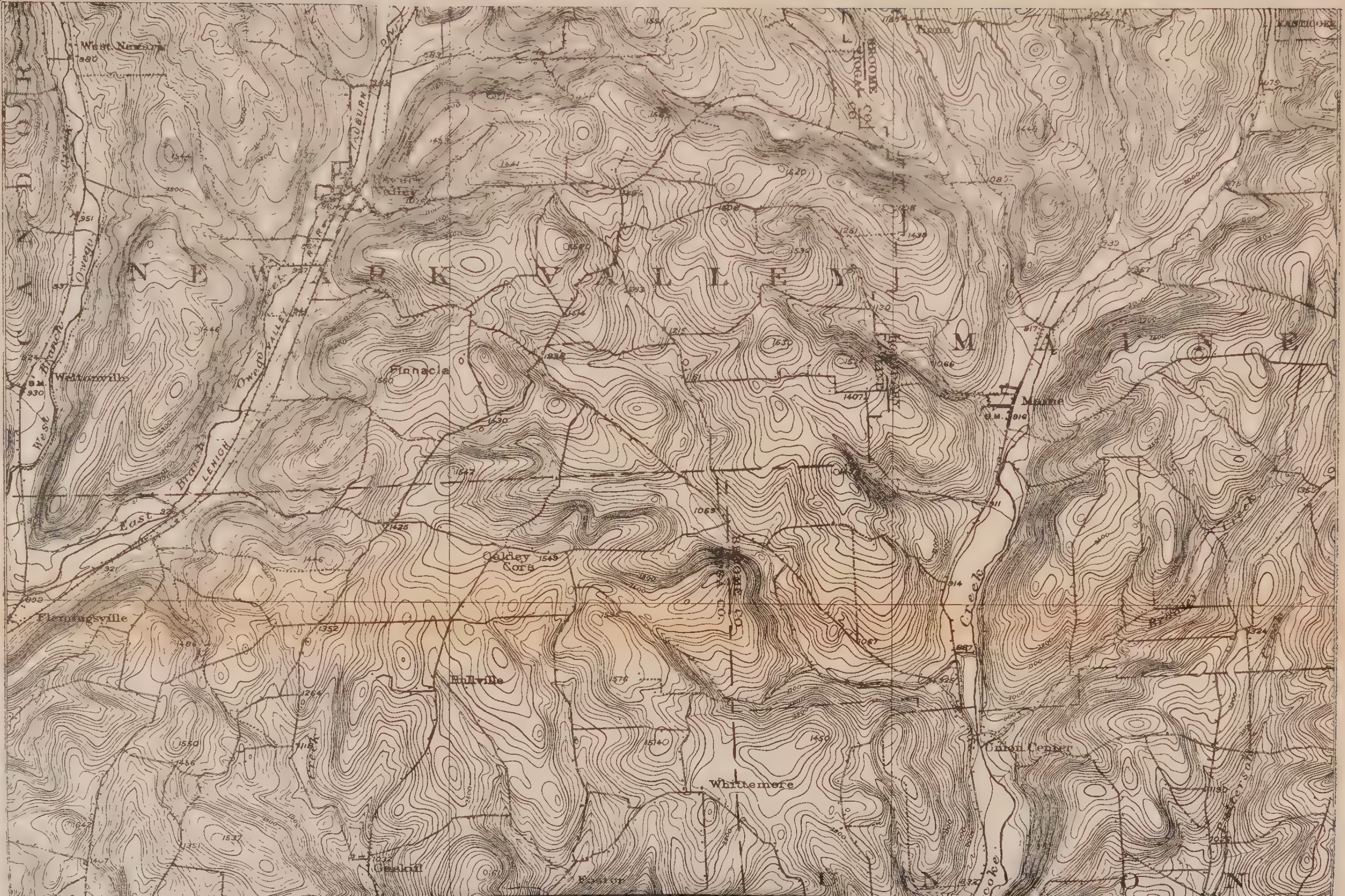
From Waverly to Owego the river valley exhibits no unusual features, but good display of the lower lake plains, especially at or near Barton and Lounsberry, and the terracing by the intrenching river. The river is flowing in the lake deposits, with a gradient of about 2 feet a mile. It has not developed good meanders, and is busy with transportation instead of erosion.

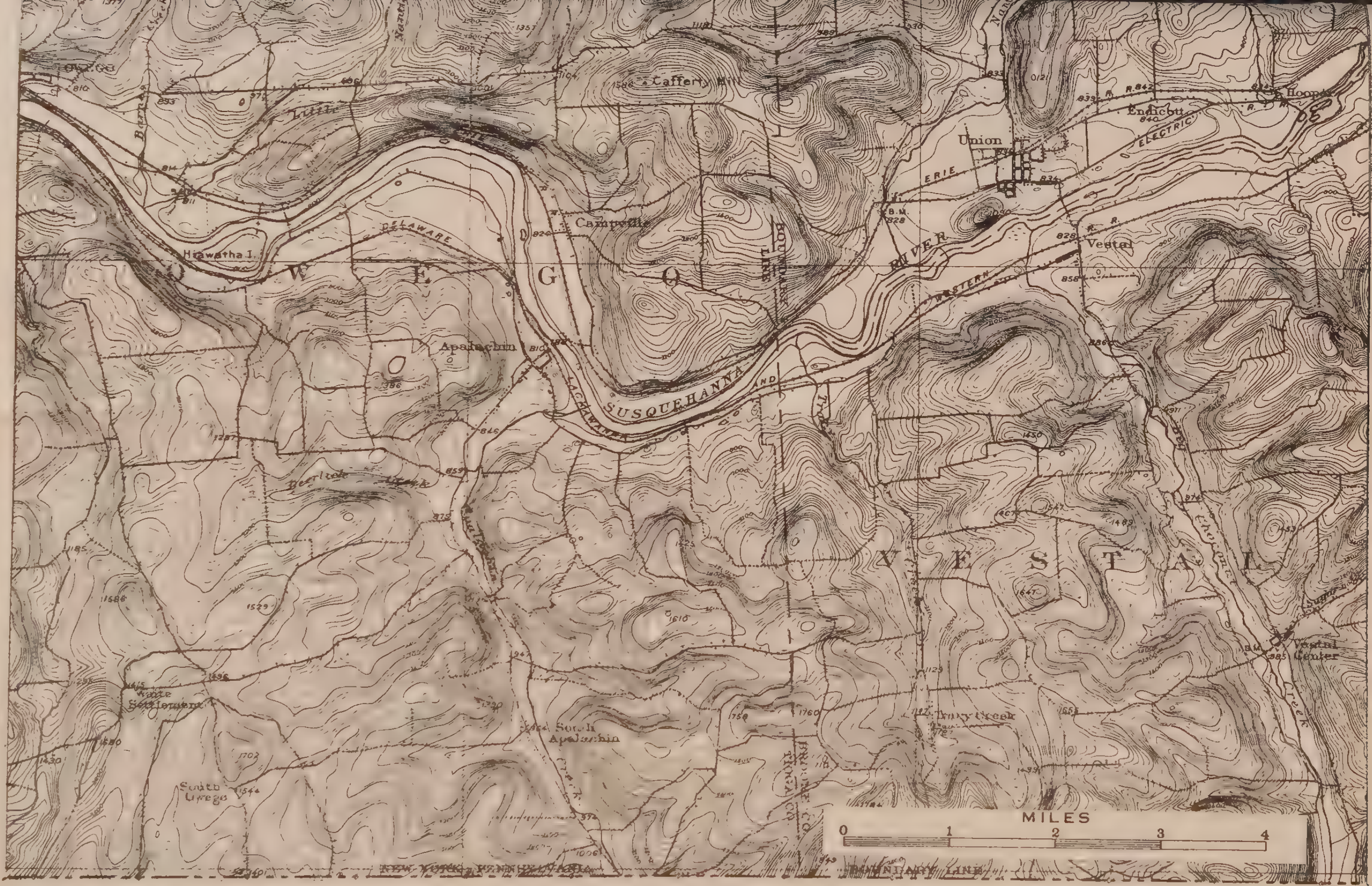
The summit level of the lake waters is not evident and has not been sought in this stretch of the valley, but going south from Nichols up the Wappasening creek the lake plains are handsome, and the lake summit is found 8 miles up the flooded valley, close to Windham Center. At the village the plain is somewhat above the lake surface and represents the creek delta.

At Lounsberry is a good plain at 880 feet, and a delta occurs at the mouth of the ravine on Hunts creek, a mile east of the railroad station. Three strong bars lie on the delta, extending north and northeast, with elevation approaching 900 feet.

Two miles north of Lounsberry are a number of large kettles, indicated on the map. Like many similar basins they prove the persistence of the buried ice blocks while the deposits remained under water.

At Owego is a wide section of the valley, at the junction of Owego creek, and the river was forced to the south side by the flood and detritus of the Owego and Catatonk creeks. The lower lake plains, although greatly eroded, are conspicuous, but the higher water has


N E W A R K V A L L E Y
M A I N E
West Newark
Weltonville
Pinnacle
Oakley Cors
Flemingsville
Bullville
Whittemore
Union Center
Maine
BROOME CO
TIOGA CO
BOUNDARY LINE
West Branch
East Branch
Owego Creek
Owego Valley
LEHIGH
AUBURN DIV
Creek
Nanticoke
Foster



Union-Endicott District

left slight evidence. The city is on the low plain, 800 to 820 feet. The plateau at the Goodrich Settlement has summit elevation of about 850 feet. Along the sides of the valley, especially on the west, evidences of standing water have been found up to 880 feet. The theoretic altitude of the summit level here is about 930 feet. This affords good illustration of the truth that a single locality is not dependable for summit water level, and that negative evidence is not conclusive.

The east and west branches of Owego creek were flooded by the Binghamton lake, and the valleys hold a fine display of terraced plains. Plate 30 shows the strong terraces at the junction of the branches, near Flemingville. The village of Newark Valley (plate 12) is on a plain 960–80 feet. Three miles north the 1000 feet contour lies across the floodplain, while at Berkshire, 6 miles north, the plains are 1060 feet. The present slope of these stream plains is at least 13 feet a mile, and with liberal deduction for the postglacial uplift they must have had an original slope of 10 feet a mile.

The Catatonk valley brought to the Susquehanna the overflow of the ice-bound waters of the Cayuga valley, Lake Ithaca, but this is considered in the next chapter.

Between Owego and Binghamton are two southern tributaries, Apalachin and Big Choconut creeks, and Nanticoke creek from the north. The river tributaries from the south, having northward flow, have a different history from the northern tributaries. The latter were flooded by the outwash from the ice sheet and filled with detritus, or "valley train" drift, and consequently these streams carried detritus into the Susquehanna lakes. On the contrary, the southern valleys were blocked by the ice sheet and their ice-bound waters, local glacial lakes, had their volume fixed by the lower passes for southward escape, and the detritus from the ice sheet was dropped in the local lake. The only detritus which these southern streams have carried into the main valley is the moderate load derived from the erosion of the present channels. Of course these southern valleys were flooded by the Susquehanna waters, but the stream deltas are some distance up the valleys, as already noted for the Wappasening.

The glacial lakes held in the Apalachin and Choconut valleys have been mentioned and their outlets located in an earlier chapter, page 27.

In the Apalachin valley the Binghamton lake extended about 3 miles, where the plains are over 900 feet. In Big Choconut valley the lake waters reached up the valley only a couple of miles, judging from the Apalachin sheet (plate 12). A mile south of Vestal the road lies on a bench at 900 feet.

The Nanticoke valley has not been examined, but the map suggests that the lake must have reached to above Maine village.

Cayuta, Catatonk and Cayuga Valleys

Ithaca, Waverly, Dryden, Owego sheets, plates 13 and 14

This district has a complex of valleys and an involved glacial drainage history. The net of valleys in the larger area is shown in plate 3. This chapter carries the story northward to Ithaca, for just as the lake waters chased the waning ice sheet into the Seneca valley, so the high water, perhaps held yet higher by drift barriers, pursued the retreating ice front into the Cayuga valley.

The south-leading valleys of Cayuta and Catatonk were partially blocked by ice and stream drift, which lifted the waters of the valleys at Spencer and Candor to yet higher levels, and these high waters reached into the two south forks of the great Cayuga valley. The water planes are shown in figures 6 and 7.

A mile east of Van Etten is the flat, swampy divide between the Cayuta and Catatonk drainage. Evidently this divide was not covered by the standing waters, at least not for any length of time. The altitude of the col is under 1020 feet, while the definite sand plains at Van Etten on the west and Spencer on the east are 1000 feet. This gives a limit figure for the ponded waters in the two upper valleys toward Cayuga.

The district of Spencer and North Spencer, the head of Catatonk creek, has exceptional interest in glacial geology. A heavy moraine was piled here, extending from a mile north of Spencer village to within a few miles of Ithaca, a stretch of about 12 miles. The outlet channels of the West Danby glacial lake (28) lie across the indefinite divide above North Spencer, with elevation 1040 feet. Very interesting features of lake and stream work are found on the east wall of the valley up to 1100 feet. Within the space of 2 or 3 square miles in this locality are found all the variety of deposits and topography associated with the removal of the glacier. Here are till-moraine and kame-moraine, high-level drainage channels in both drift and rock, deltas in lateral ice-dammed waters, and by free flow into open-lake waters. The history of the ice-front recession in the Cayuga valley is on record here from the time of the glacial outwash and the building of the Spencer moraine,

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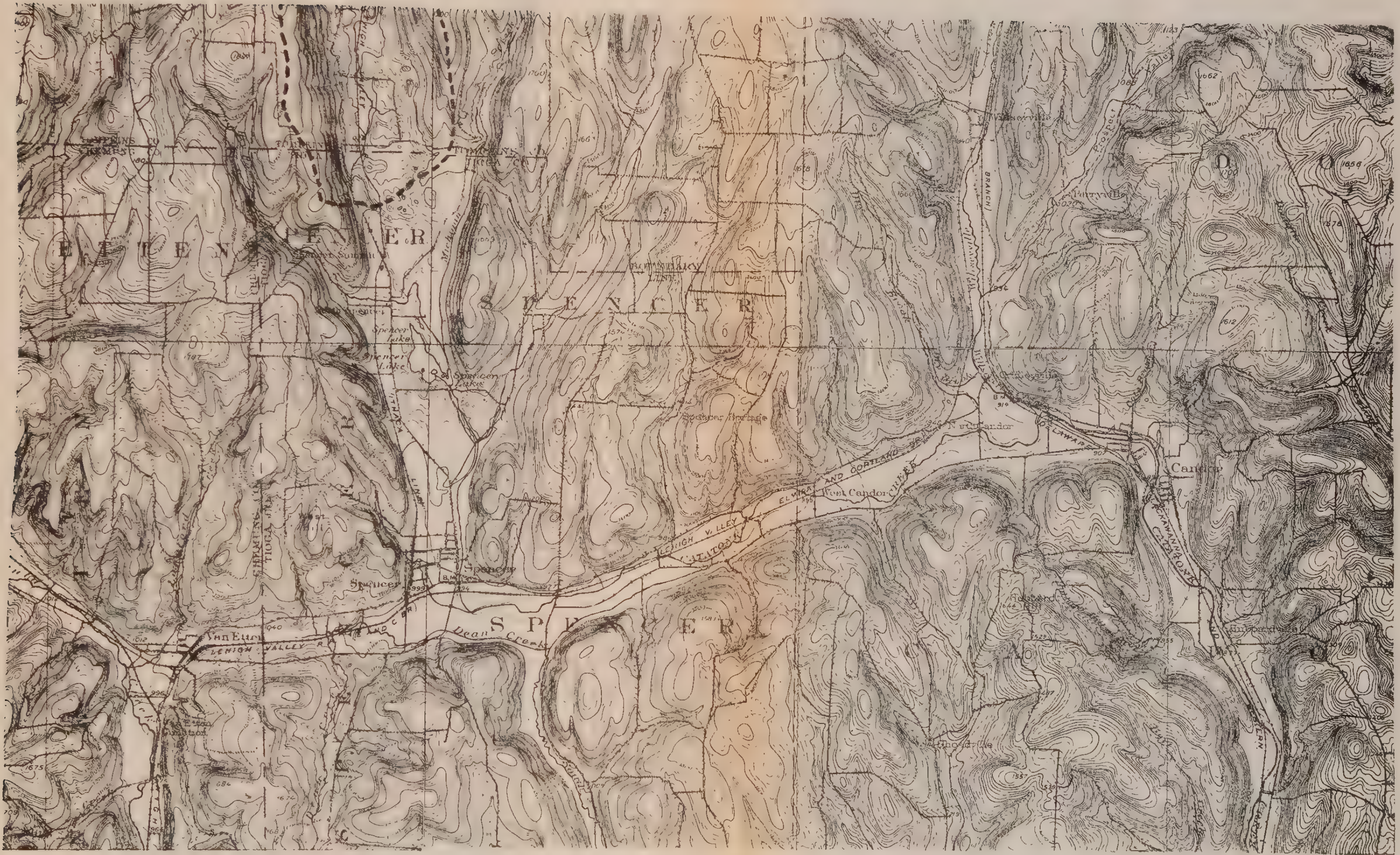
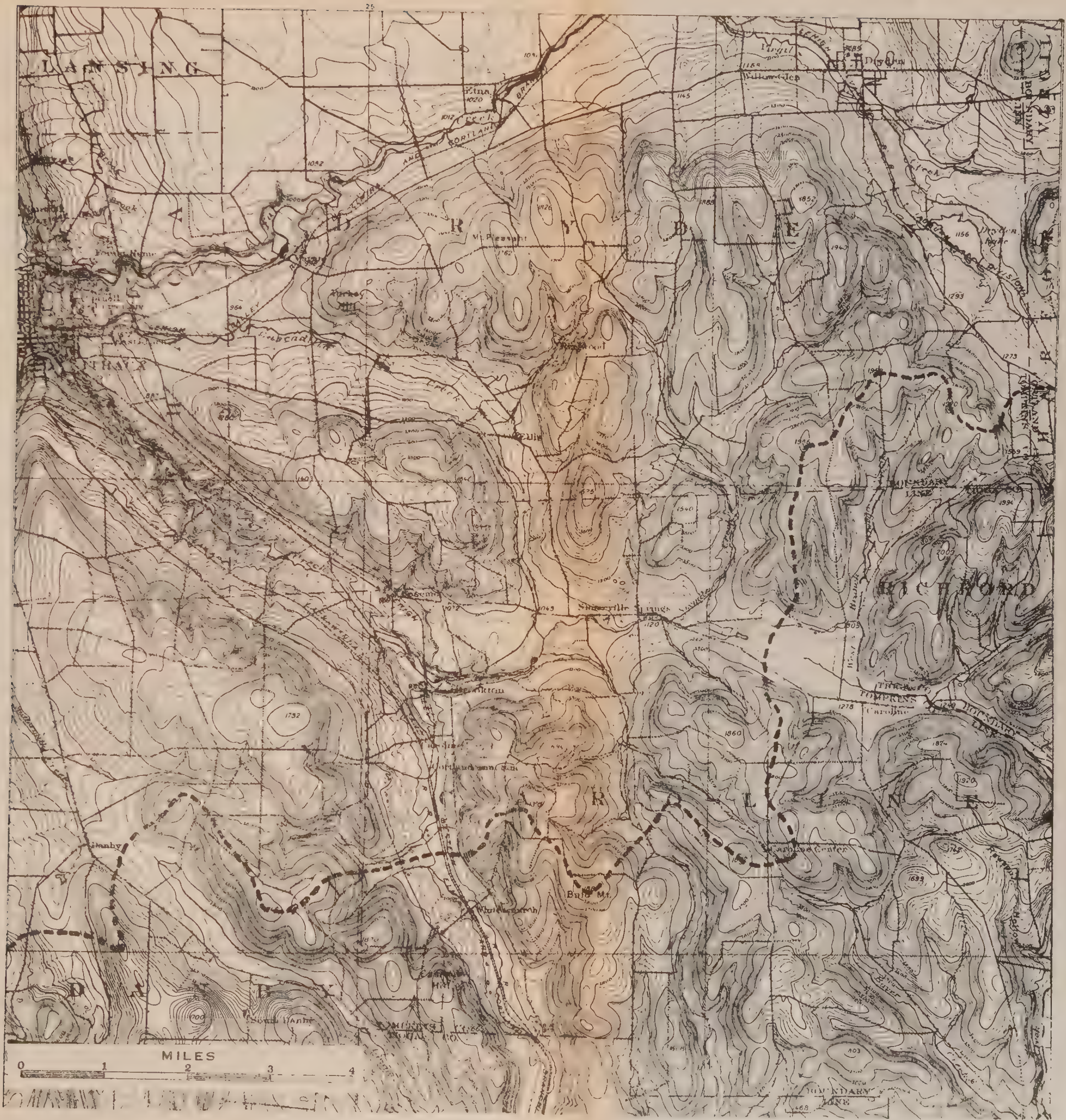
BULLETIN 256 PLATE 13



Van Etten–Spencer–Candor District

The broken line marks the divide between northward and southward flow



ITHACA–BROOKTON DISTRICT

The broken line marks the divide between northward and southward drainage

through the life of the West Danby lake and until its extinction, with the establishment of the present drainage. This complex of geologic phenomena affords an exceptional opportunity for intensive study and precise mapping of a small area.[1]

The outflow of the glacial waters in this west fork of the Cayuga valley, the West Danby lake, past North Spencer and Spencer, was eastward and then southward by the Catatonk creek to the Susquehanna water at Candor and Owego (plate 13).

The east fork of the Cayuga valley now claims attention, and here we find another interesting district with involved history (plate 14). Willseyville creek, which joins the Catatonk at Candor, heads at White Church on the divide 9 miles southeast of Ithaca. This divide is traversed by the capacious outlet channel of the glacial Lake Ithaca (30, page 47), with altitude 990 feet. But 2 miles north, at Brookton, is a handsome terraced gravel plain with elevation up to 1040 feet; while northeast of Brookton the valley of Six Mile creek has extensive plains reaching to Slaterville Springs, and up to 1120 feet.

The Slaterville plains were formed in a local glacial lake held in by an ice tongue that covered Brookton and blocked the valley. The first outlet of the Slaterville lake was eastward across the swamp col, at about 1270 feet (see the Dryden sheet), to the west branch of Owego creek. A second and lower outlet was the clean-cut rock channel on the nose of the hill south of Brookton, having an altitude of 1075 feet. The lower Slaterville plains correlate with this later outlet.

There remains the complication in the strong gravel plains out in the open valley at Brookton, with elevation up to 1040 feet, or 50 feet over the White Church divide and outlet channel. The form and relation of the latter do not indicate much down-cutting. The probable explanation is that drift-barrier lake waters followed the receding ice front up the Catatonk and Willseyville valley and into the Cayuga valley, similar to the invasion of the Seneca valley previously described. Benches and terraces and deltas lie on the valley sides over White Church and southward to Owego, but in the constricted valley at Willseyville and below Candor these may represent valley filling and a graded stream instead of lake.

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[1] The accurate contouring of this locality with five-foot interval, and the correct diagnosis of the origin of the deposits with their relation to the topography, and the clear translation of the story of events, would be worth a master's degree to both the topographer and the geologist. The area is commended to the department of geology of Cornell University.

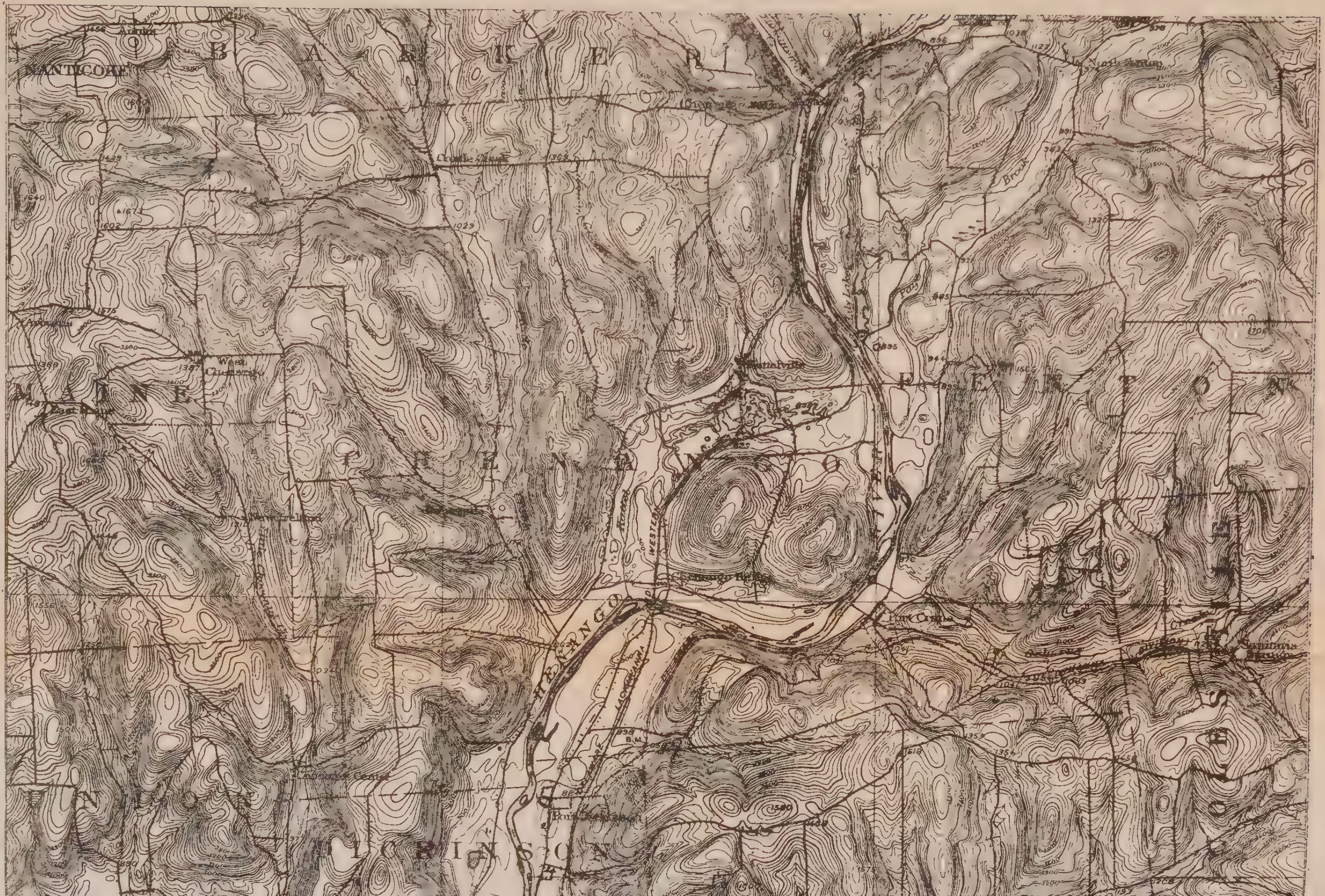
Binghamton District

Binghamton sheet, plate 15

The city of Binghamton is a good example of the influence of physical features on the location and growth of cities. The city stands on inferior lake plains, from 860 to 900 feet elevation, the river falling from 830 to 820 feet. The central and business part of the city is on ground at 860 feet, and fragments of the eroded and excavated gravel plains are conspicuous in the western part of the town, especially south of Main street, at 900 feet. North of the city in the Chenango valley are extensive remnants of plains which once filled the valley. At Hillcrest these are over 900 feet, but over 920 feet in the Kattel loop of the old valley. At the Chenango Valley cemetery the plain rises to the full height of the Binghamton lake, about 950 feet at this point. A mile southeast of Port Dickinson is the delta of Brandywine creek, which shows good delta structure. The factory of the Binghamton Brick Company stands on the southern part of the plain. The subsiding lake and the Chenango river have eroded the delta so as to give a steep west-facing front. The Lackawanna railroad lies below the cliff front, while the Delaware and Hudson railroad has a deep cutting through the delta, exposing the upper and later beds which are coarse, shingly stuff, shown in plate 31. Between the two railroads, on the extension of Blanchard avenue, is the gravel pit of Peter Merrill, which gives an interesting section of sand and gravel beds. The student may find here an excellent record of the events connected with (1) the receding ice front, shown by (2) the gravel from the glacial waters, and succeeded by (3) land stream deposition of coarse stuff, poured into (4) lake waters of falling level, and (5) erosion by the river and creek.

In the eastern part of the city, about half-way to the Binghamton State Hospital, a high-level delta was built by Chamberlain creek. The Fairview School and the Chenango Silk Mill, on Robinson street, stand on the lower plain with altitude of about 900 feet. Passing north up the creek and the unimproved Glen avenue, the delta gravels underlie Bradley, Griffith and Nash streets. The upper limit of the delta appears to be near Monroe street, with height about 945 feet.

On the south side of the valley the street railway to Ross Park is on a stream delta, the terminus of the line being at the apex of the fan, and above the water level. A mile west of Ross Park is a road corner with map elevation of 888 feet, on the city line. The


NANTICOKE
BARKER
MAINE
CHENANGO
FENTON
UNION
DICKINSON
West Chenango
Brook
WESTERN
CHENANGO
LACKAWANNA
Port Crane
Chenango Bridge
Castle Creek
1029
1375
1387
1602
1675
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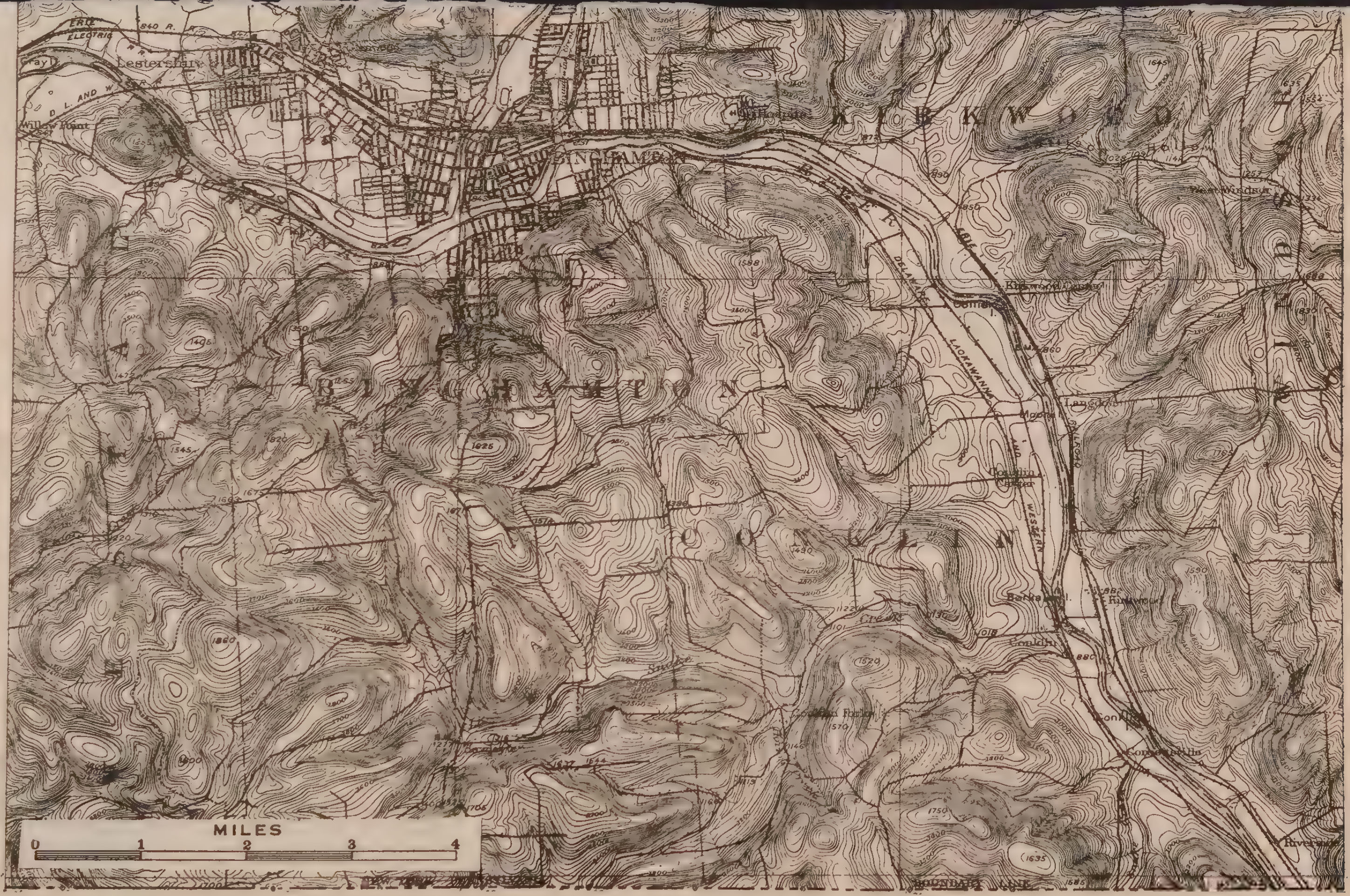
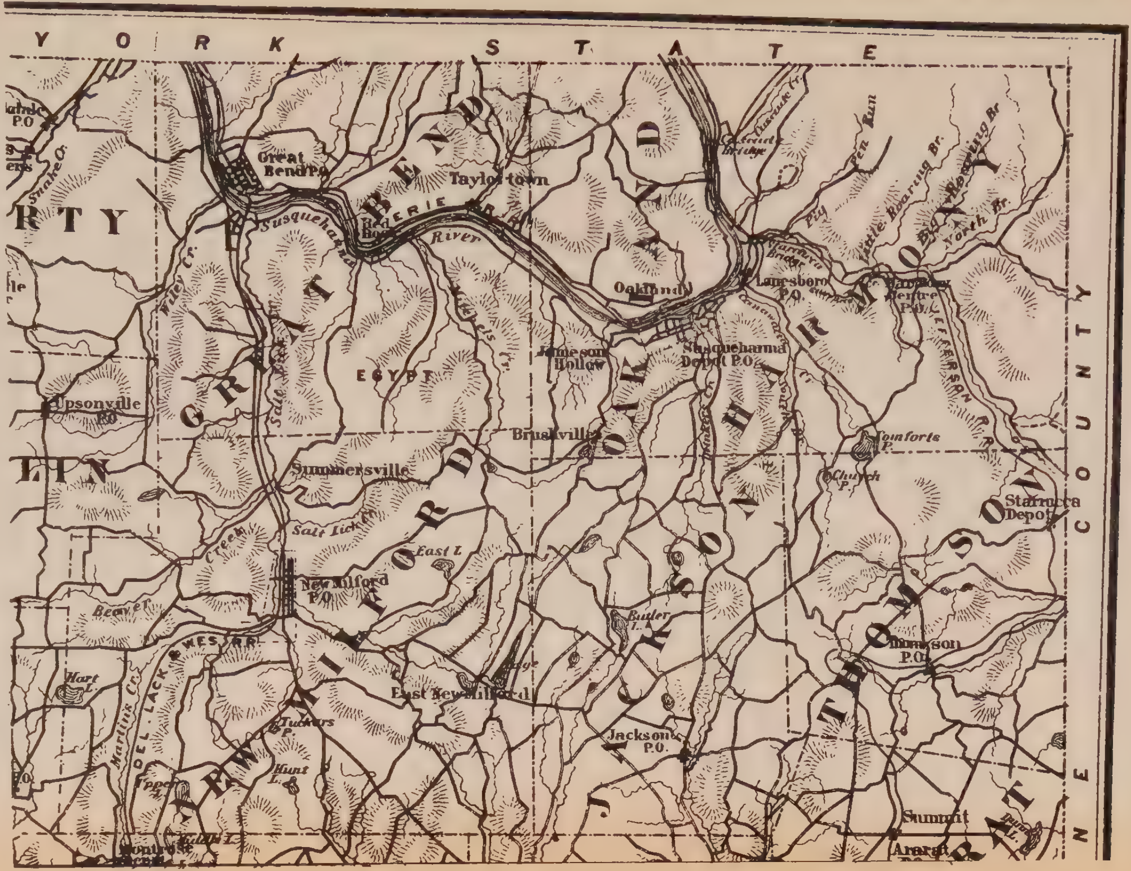


Binghamton District



GREAT BEND–LANESBORO DISTRICT

road is on the front of a delta built by a brook from the south, and a farm residence stands nearer the water level. Here, as in many cases, it is difficult to determine the precise lake level on the delta, as the delta shades up stream into the flood plains, and laterally the water deposits shade into the modified land surface. Similar deltas will be found at the mouth of all the streams flowing down from the highland. The difficulty in determining the summit level of the lake gives interest and value to the study.

The Binghamton sheet shows the river and valley features south to the state line, about 3 miles below Great Bend. The evidence of standing waters is abundant along both sides of the valley, in the uniformly bedded and well assorted sand and gravel. The tributary streams have rather poorly developed deltas. A good delta plain occurs at Langdon flag station on the east side of the valley, contributed by two nameless brooks. The eroded front is clearly seen from the highway. The summit of silty sand, is about 925 feet elevation. Lying south of the parallel of Binghamton the locality has been less uplifted. The lake plane at Great Bend is taken as 915 feet. At Binghamton the water plane is about 945 feet.

Professor Brigham (25, page 29) gives well records in the Binghamton district, ranging from 55 feet to rock in the southern part of the city to 160 feet a mile north of the railroad stations. It is probable that the axis of the buried valley lies much north of the river, as the river has been pushed over against the south wall of the valley by the delta of the Chenango. Russell Shear, whom Professor Brigham quotes, informed the writer 219 feet was the depth to rock at Port Dickinson, and 240 feet was the depth to rock at Union. The latter had ground surface at 820 feet, making the altitude of the rock bottom at Union 580 feet.

Great Bend–Lanesboro District

Plate 16

From above Lanesboro to below Great Bend, about 15 miles, the southward curve of the Susquehanna river lies in Pennsylvania. The lack of topographic maps is the more unfortunate as this most interesting stretch of the river valley has the only postglacial rock ravine, the only drift dams which are well preserved, and the largest and finest esker in the entire length of the river.

As this curve in the ancient valley lay athwart the general direction of the ice movement it was favorable to the catchment of glacial drift and was partially filled with moraine. Two miles above Great

Bend village the moraine blockade was complete. The ponded water found escape along the north side across a tongue of rock that projected from the north wall, and has cut a short rock ravine. This was described by I. C. White in his report on Susquehanna county (2) as follows:

> About 2 miles above Great Bend depot the Susquehanna river flows through a narrow gorge, only 100 yards wide, where it is hemmed in by walls of outcropping strata (page 91).
>
> . . . But this is evidently a new cut, since the ancient channel of the stream may now be seen one-half mile farther south, filled with drift which silted it up during the Glacial Epoch; thus it is possible that in all cases where a rock bottom is now seen in the Susquehanna it is not flowing over the ancient or preglacial channel (page 93).
>
> The appearance of the Susquehanna valley is such as to indicate the presence of an old buried channel of considerable depth (page 93).

The Erie railroad follows the north side of the river all the way from Binghamton to Susquehanna village, and its cutting for the tracks has changed the north wall of the short ravine. The vertical south wall is about 100 feet high, and the width of the river is about 300 feet. The length of the ravine is less than 1000 feet. The highway passes over the ridge above the railroad and gives good views of the features (plate 32).

The old valley at the villages of Susquehanna and Oakland is probably the narrowest in the entire valley, and here is another drift dam which held temporarily to high level the waters in the valley above. An early overflow of the morainal lake was over the north side of the barrier, close west of Oakland, where cataract scourways cut by the outflow have elevations of 985 and 990 feet. The trench finally cut by the river is on the south side of the valley. At Susquehanna village the evidence of standing water is found on the valley side to 1010 feet. At Lanesboro the delta built by Canawacta and Starucca creeks gives a terrace at 1004 feet. Since the level of the Binghamton lake at Great Bend is 915 feet it appears that the Oakland moraine dam held up the Windsor-Harpursville water about 100 feet.

The third special feature in this district is the massive Lanesboro esker (plate 33). This is nearly 2 miles long, on the west side of the river but in the middle of the curving valley extending from Susquehanna around to northwest of Lanesboro.

Another attractive object in this locality is the famous Starucca viaduct at Lanesboro, which carries the Erie railroad across the

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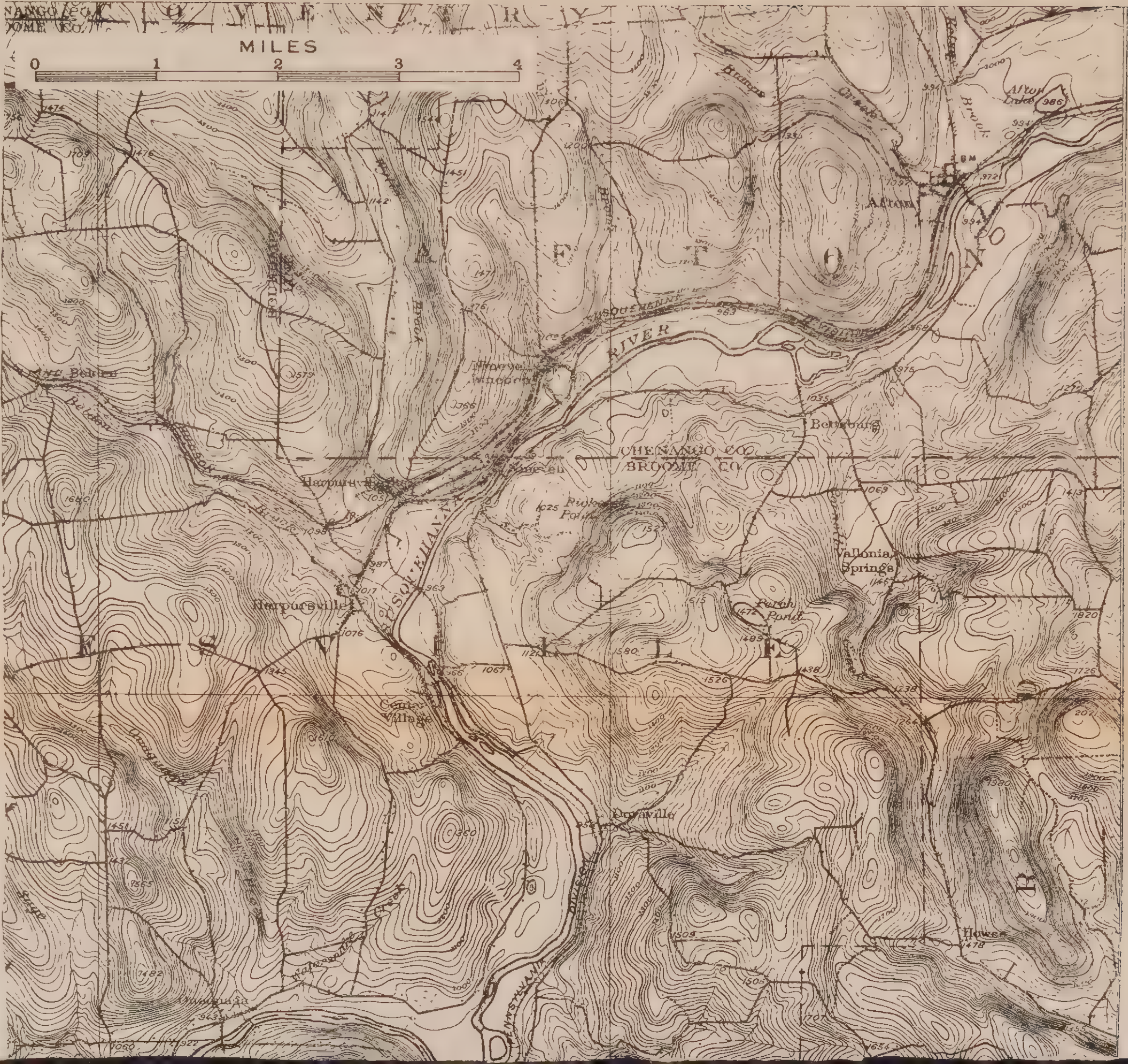

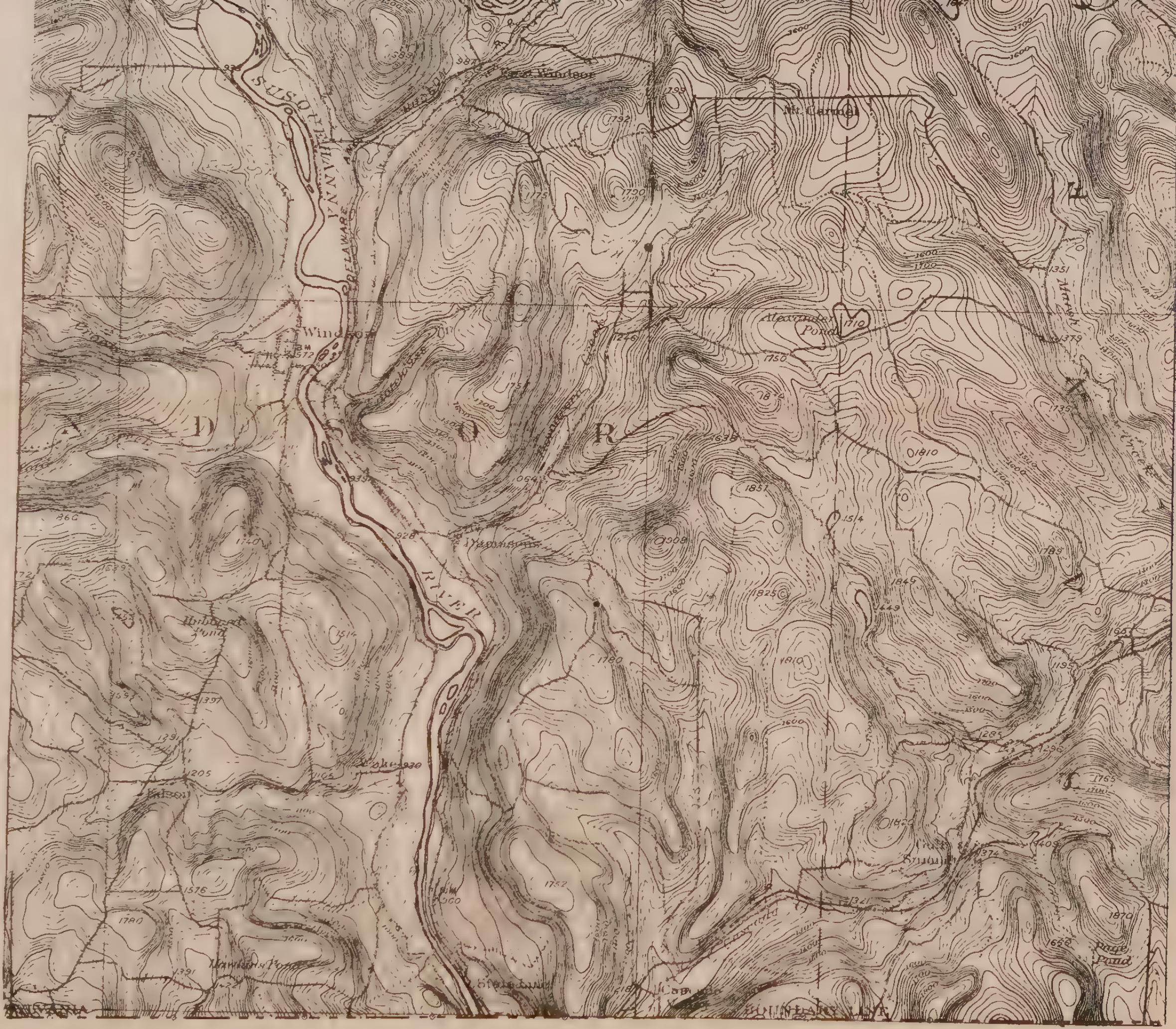

Windsor–Harpursville District

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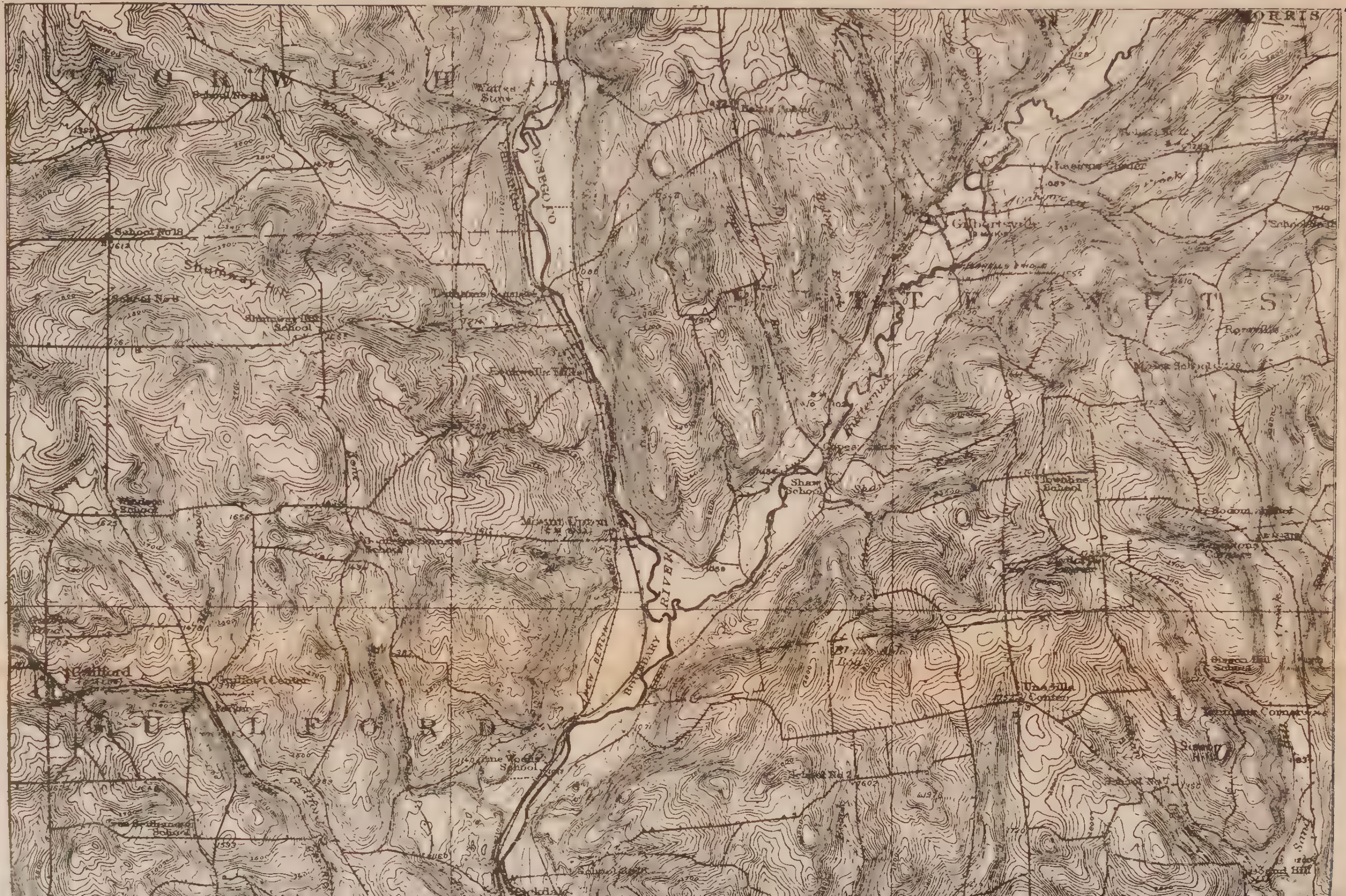
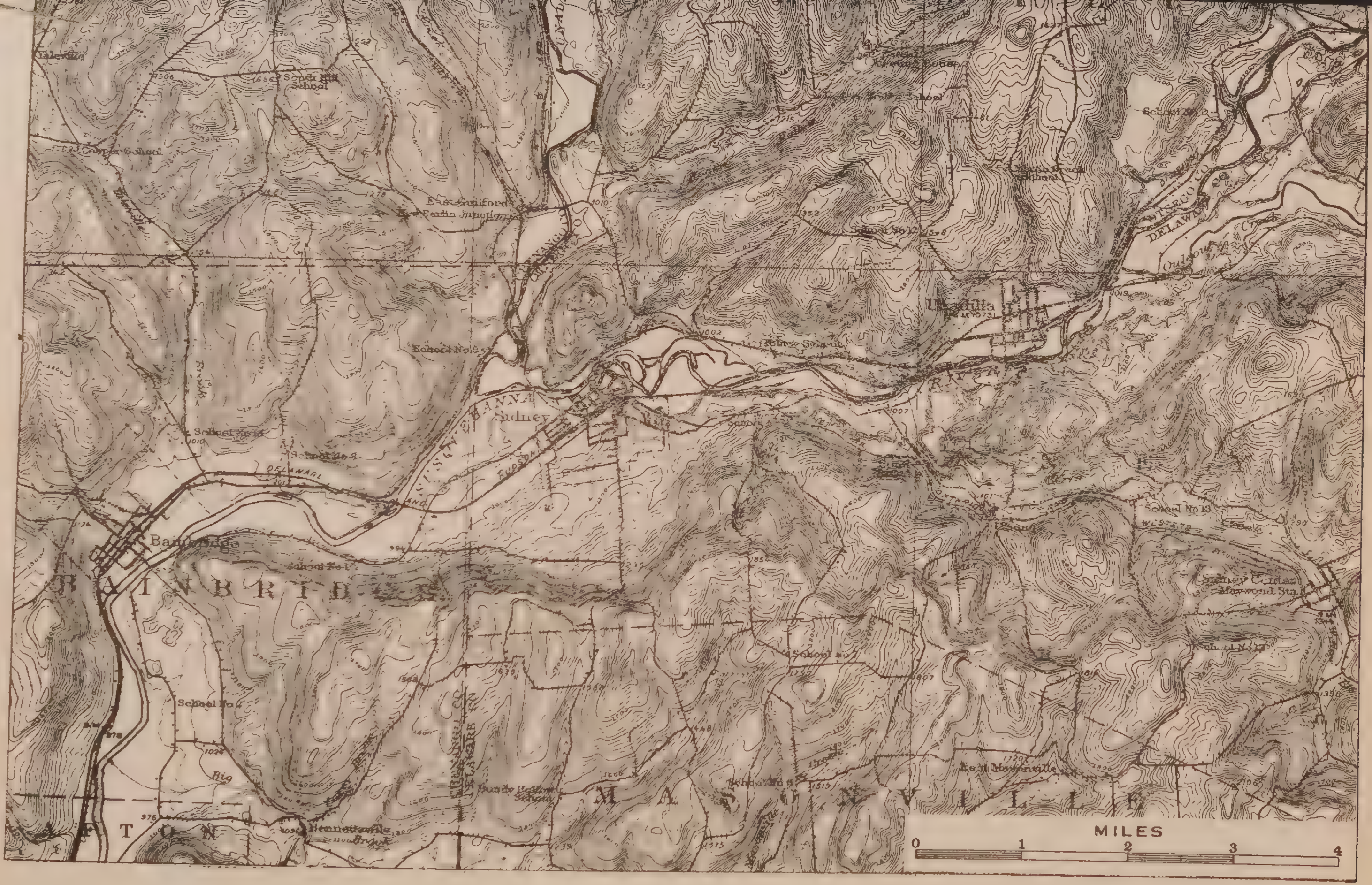
STATE MUSEUM

BULLETIN 256 PLATE 18





Bainbridge–Sidney–Unadilla District

Starucca valley. It is a massive bridge of cut sandstone, finished in 1849.

The fuller study of the geography and geology of this very interesting district must await the topographic maps. For altitudes at present we must depend on the track elevations of the railroads. These are: for the Lackawanna road, Hallstead 903 feet; for the Erie road, Great Bend 880, Hickory Grove 896, Susquehanna 910, Susquehanna Junction 983; for the Delaware and Hudson road, Lanesboro 956 feet.

Windsor-Harpursville District

Nineveh sheet, plate 17

The district covered by this map extends from the state line to 2 miles above Afton, a distance of 24 miles. In this stretch the river falls about 80 feet, being 960 feet at Afton and 901 feet above the dam at Windsor. The lower plains of the glacial waters are conspicuous and the villages are built on deltas of the tributary streams.

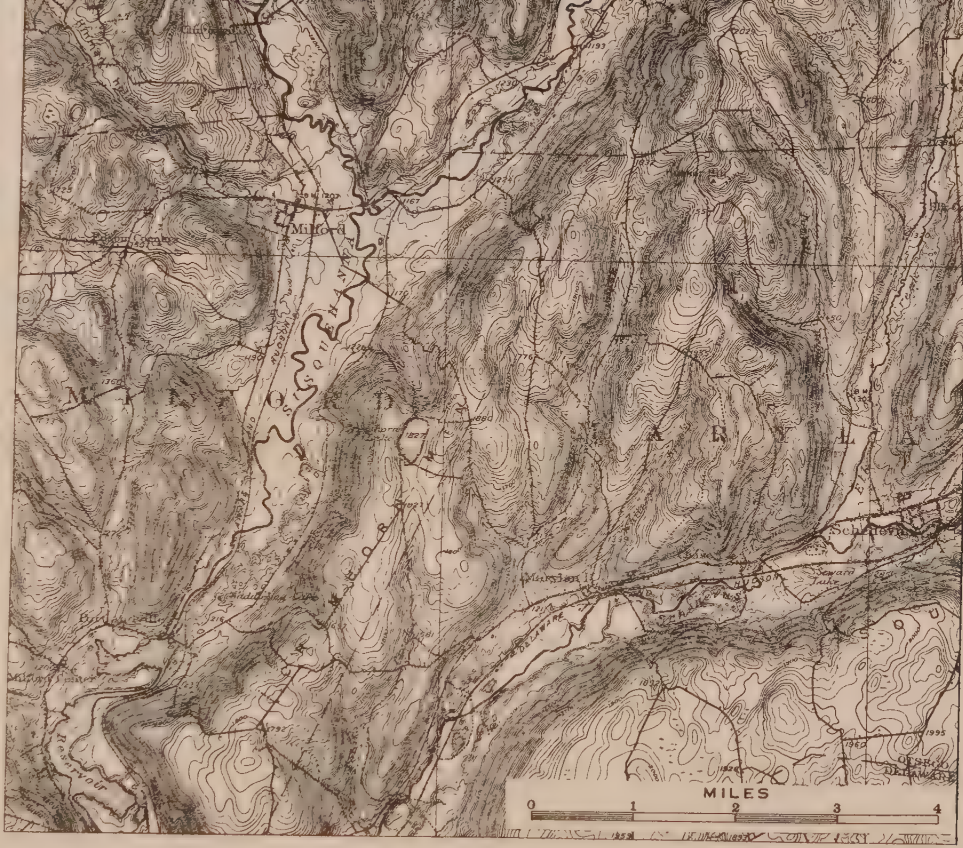
One of the finest displays of plains in the whole length of the river is on the east side of the valley, opposite Harpursville and Nineveh Junction. They are clearly seen from the Delaware and Hudson railroad lines. By leveling from the United States Geological Survey bench at Harpursville Station the highest of the wide terraces is 1075 feet, which is the theoretic elevation as shown by the profile (figure 8).

Bainbridge-Unadilla District

Unadilla sheet, plate 18

This map is of recent survey, with fine expression, and the plains can be recognized on the sheet. Here we find the junction of the Unadilla valley, which in the beginning and closing phases of the glacial flow brought in the waters of the Mohawk valley and the Adirondack highland (plate 8).

The three villages of Bainbridge, Sidney and Unadilla stand on lower plains of the glacial detritus. The fall of the river on this quadrangle is about 55 feet in 17 miles by the valley. The summit plains rise from about 1100 at Bainbridge to 1160 feet on the east edge of the area, near Wells Bridge. The high-water features appear strong the whole length of the valley, but especially so above Unadilla. Here a heavy kame area, with high relief and numerous kettles, has been top-leveled by the standing waters. The terraces do not appear to good advantage from the railroad as this lies too low.



Cooperstown District

supplied the main valley with much detritus. The small area covered by the Delhi sheet holds much of interest for detailed study. Indeed the entire district is excellent for the study of glacial and stream phenomena, and is commended to the students of the Oneonta State Normal School.

Cooperstown District

Cooperstown sheet, plate 20

This map also has good detail and the reader can recognize the glacial features. Kame areas with numerous kettles are prominent deposits above Portlandville, also at Index and in the tributary valleys of Schenevus, Cherry and Oak creeks.

The river level rises from about 1150 in the Portlandville reservoir, judging from the map contours, to 1194 in Otsego lake, the distance being 13 miles by the valley, but nearly twice that by the river meanders.

Excellent remnants of the high plains occur in the Portlandville district, where the kettles indicate morainal deposits and a possible blockade of the valley. A good display is found at Milford, and especially from Hartwick Seminary to Cooperstown. The valley of Oaks creek, from Index north to Schuyler lake holds a great volume of kame and lake detritus, with huge kettles above Fly creek. A particularly fine example of leveled kames with numerous large kettles, a so-called "pitted plain," is seen at Index (plate 35). Some of the funnels or inverted cones are 30 to 50 feet deep.

The village of Cooperstown is mostly on a higher plain which in the western part of the town is 1260 feet. Kettles occur in the village, and it is probable that the material of the plains is glacial, or kame-moraine, and has been leveled by lake waters.

Otsego lake is said to be 180 feet in depth. Borings behind the building of the A. H. Crist Company, on Main street, went 160 feet to rock (letter from C. F. White). These data make the elevation of the lake bottom 1014 feet, and rock under the village 1070 feet. It is evident that Otsego lake, like nearly all the lakes of the glaciated territory, is due to the drift blockade of an old valley, or is a drift-barrier lake.

At the head of Otsego lake (plate 21) the standing water evidence is clear in the silt and sand plains. The elevation of the lake is given as 1194 feet. Near Springfield Center the sand plains are over 1260 feet. The wide plains above Hyde Bay, toward East Springfield, reach 1270 feet. Here we find the extreme northern reach of the Susquehanna lake waters in the main valley. The profile of these northern plains is given in figure 8.

SPRINGFIELD GLACIAL CHANNELS

Richfield Springs and Canajoharie sheets, plate 21

The singular and unique features in the Otsego lake region are two channels carved by glacial waters, with torrential flow, south of the Mohawk divide. These two channels have singular relation to the topography and to the drainage history. The locality had brief mention in a former paper (34, pages 19-24).

Six miles northeast of Otsego lake are two cols on the divide which separates the waters of the Susquehanna from those of the Mohawk. Another col is a mile above Cherry Valley, at the head of Cherry Valley creek. The three cols are indicated in plate 21. Their elevations are as follows: Summit lake 4 miles above Springfield Center, 1360 feet; East Springfield, 1 mile north, 1420 feet; Cherry Valley, 1 mile north, 1410 feet.

The pass at Cherry Valley has been normally cut and shaped by stream flow. It is a typical small channel across a divide. It did not carry a heavy flow, nor for a long time; but waters from the Mohawk side passed across to Cherry Valley creek in time and volume sufficient to produce distinct channel form (plate 39).

The two Springfield cols have not been cut distinctly by flow of water across them, but the remarkable condition is found of heavy, torrential flow and rock erosion immediately below the water-parting line. The channels are shown in the map (plate 21). A mile west of Willse hill, and 3 miles north-by-east from East Springfield other sharp channels are found, but a mile south of the divide and beneath it in altitude.

When we observe that the Cherry Valley channel is only 10 feet lower than the East Springfield notch and 50 feet higher than the Summit lake col, it is apparent that there must have been some interference with the free flow of Mohawk waters across the divide. This is further emphasized by the existence 15 miles west of the Summit lake col of a capacious river channel across the divide at Cedarville, with elevation of 1220 feet, or 140 feet lower than the uncut Summit lake notch. The explanation is found in the physical conditions of the waning glacier in the Mohawk valley during its latest phase, and the relation of the ice body to the land topography. This relation of the ice lobes is shown in plates 7 and 8. In the reduction of the Quebec glacier a stage was reached when only a neck or strait of ice lay over the Mohawk valley (plate 7). The Adirondack highland was then partially bare and the precipitation on the

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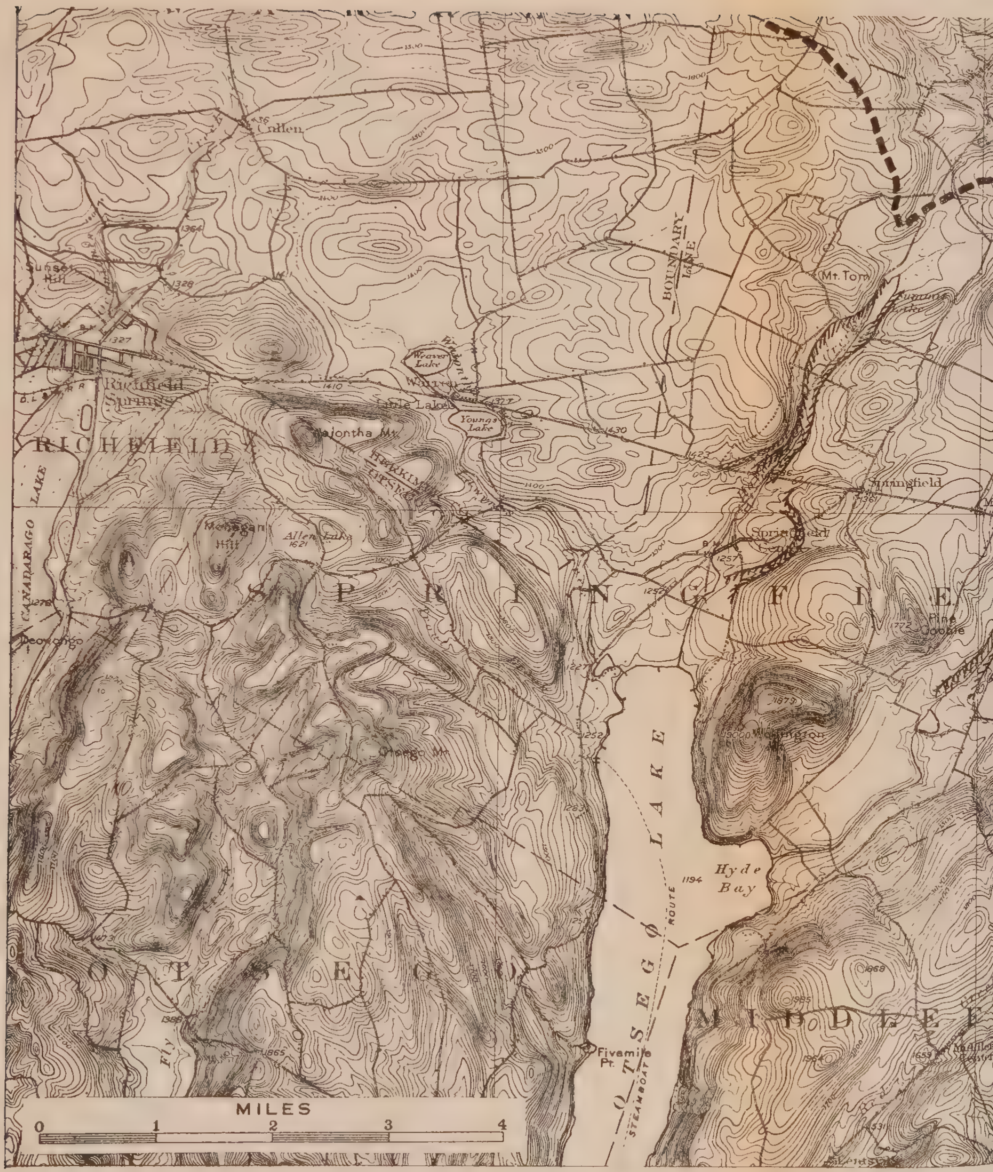
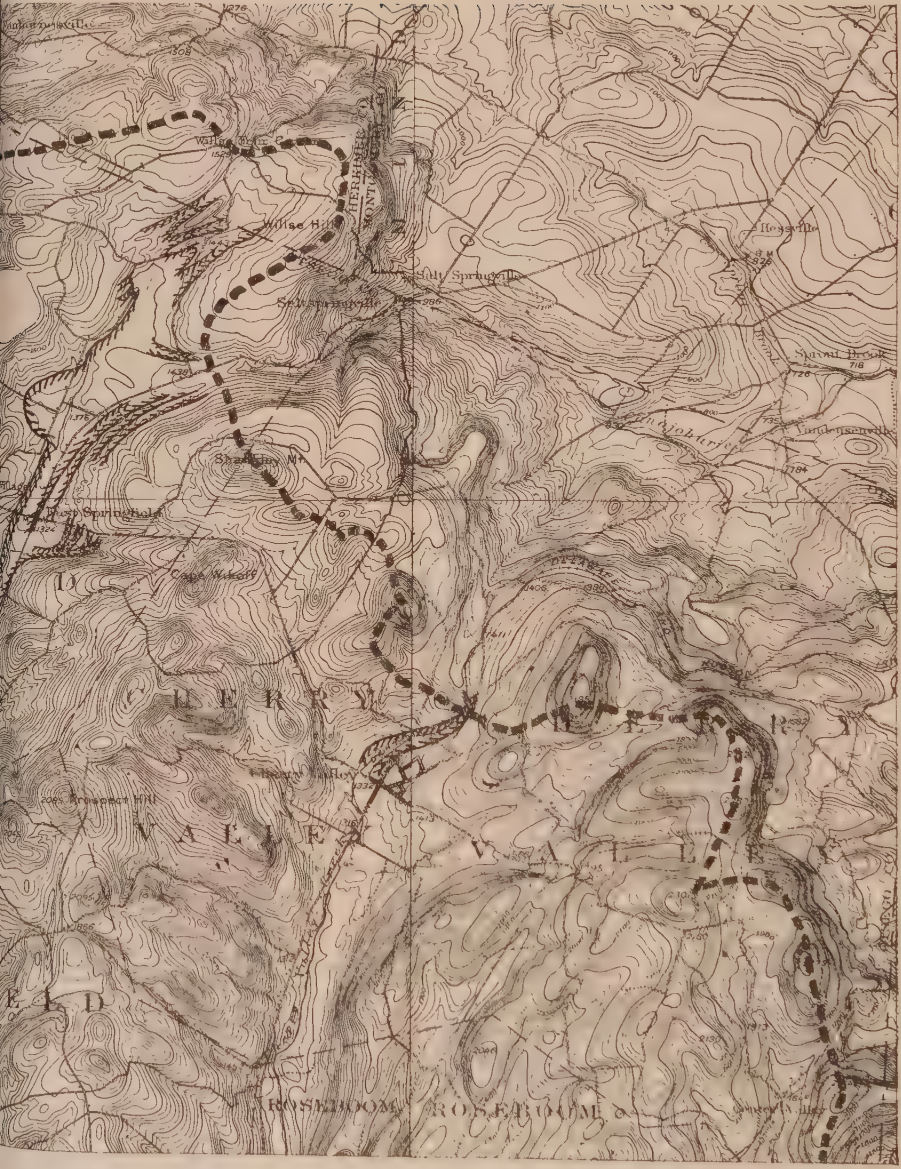


Springfield District; Head of

The broken line marks the divide between Mohawk and Susquehanna



HE SUSQUEHANNA RIVER

nage. Channels of glacial rivers are shown south of the divide exposed area and the water from the melting of the enclosing ice had no possible escape except across the Mohawk ice strait. Such outflow must have been at the lowest or weakest section of the ice strait, which was probably where the westward flow up the valley from the Hudson ice lobe met the eastward push of the Ontario ice lobe. At this locus of head-on collision the ice eventually became stagnant and melted, giving place to a lake between the opposing ice tongues (plate 8). The locality of weakness and lower elevation in the surface of the ice strait appears to have been opposite the headwaters of the Susquehanna river. While the south edge of the ice strait still covered and protected the cols, and the land divide, the waters from the Adirondack area poured across the neck of ice, fell on the land with torrential force and passed down the valleys to the Susquehanna river. The East Springfield channel especially shows the effects of torrent flow on limestone rock.

When the former paper (34) was written the East Springfield channel had not been seen. Here the limestone channel shows fluting along the east side, possibly partly due to ice abrasion but later to stream flow along the east margin of the tongue of ice that passed across the col and pushed some distance down the valley. Plate 37 shows some of the erosion forms. There are interesting details here which maps and photographs do not readily exhibit. The erosion phenomena here are not confined to the middle of the valley but appear on the east side, with evidence of the shifting and spasmodic flow which naturally accompanies a changing ice margin. They also indicate a volume of flow much greater than could be supplied from the melting of the valley ice lobe. The evidences of lateral drainage appear up to about 100 feet above the East Springfield corners, the latter being 1328 feet above tide. The sharp channels cut in rock by the lateral streams are seen east of the village, on the south side of the road. The high benches on the east side of the valley are seen extending northeast of the village for more than 2 miles. Some of these features are shown in plates 37 and 38.

Some of the higher, bare-rock ledges may be partially shaped by ice erosion, as mentioned above, for the valley surfaces in general exhibit a smoothing or drumlinizing effect, and a tendency to horizontal lines. Plate 22 shows numerous west-pointing drumlins which were built by the earlier and stronger westward push of the Hudson-Mohawk lobe.

The detritus carried by the two Springfield rivers was swept into the Cooperstown lake and was spread out to form the wide plains at the head of Otsego lake, and especially above Hyde bay, with elevation of more than 1260 feet.

The Cherry Valley channel represents free flow across the divide from a lake on the Mohawk side, the ice margin being removed from the land at that point. The short channel on the col and the weak channel features at and below the village rule out any large and long-life stream. This suggests that the Cedarville channel, 21 miles west and 190 feet lower, drew the water from this district. It also appears that the Cedarville pass became effective, by the waning of the Ontario ice lobe, before the Springfield cols were relieved of the ice cover, for otherwise those notches in the divide would have been cut by outflow, like the Cherry Valley pass. It is possible that the Cedarville pass might have had an experience similar to that of the Springfield cols, but if so the later and very heavy river flow has destroyed the glacial features. Plate 8 shows the supposed relations of the ice, lake and river during the Cedarville outlet stage.

It should be borne in mind that during the time of the removal of the glacier from this district the land there was some 300 feet lower than it is today.

COLS ON THE SUSQUEHANNA-MOHAWK DIVIDE

Winfield, Sangerfield, Morrisville sheets, plate 22

In regard to the glacial waters, the two Springfield cols and the Cedarville and Cherry Valley passes represent two distinct types of channels. West of these are several passes which carried glacial water but of a type quite unlike either the Springfield or the Cherry Valley.

For comparison of the passes which carried overflow of the glacial waters from the Mohawk valley to the Susquehanna drainage system, all the cols are listed below, pas[illegible] from east to west.

1 Cherry Valley, 1410 feet; head of Cherry Valley creek

2 East Springfield, 1420 feet; head of Shadow brook, to Otsego lake

3 Summit lake (Springfield Center), 1360 feet; head of Hayden brook, to Otsego lake

4 Cedarville-Chepatchet, 1220 feet; head of Unadilla river

5 Cassville (Richfield Junction), 1260 feet; head of west branch of Unadilla

6 Sangerfield (Waterville), 1250 feet; head of Sangerfield river, to Chenango river

7 Bouckville, 1160 feet; one head of Chenango river

8 Whites Corners (Morrisville Station), 1180 feet; one head of Chenango river

9 Peterboro (Morrisville), 1300 feet; main head of Chenango river

Of these nine passes across the divide between the Mohawk and Susquehanna waters the only ones which carried a free stream from open lake on the Mohawk side are the small Cherry valley and the capacious Cedarville. The latter was the outlet of the early high-level Mohawk water, the Herkimer glacial lake, shown in plate 8. Referring to the list above, however, it is seen that two other passes, numbers 7 and 8, at the two proper heads of the Chenango valley, are much lower than the Cedarville channel. The explanation would seem to be that these two low cols were blocked by the Ontario ice lobe during the life of Lake Herkimer. They lay so far west that they were shut off from the open lake by the ice front which pressed against the high ground between Cedarville and Bouckville, until the weakening of the Hudson ice lobe on the Helderberg scarp, southwest of Albany, permitted eastward escape for the Mohawk valley waters (34, plate 14).

All the passes west of the Cedarville, however, except the Peterboro, were flooded by glacial outflow, and constitute the peculiar third class of water passes. The two river systems of which they were heads, the Unadilla and Chenango, had a glacial history similar to that of the Susquehanna, and their valleys appear to have been also flooded to the heads, at the ice front. Since the region was 300 feet lower than it is today, the valley gradients were less. A series of morainal lakes probably carried standing water over the cols to the ice front. Today the line of water parting at the four lower cols (5-8) lies on wide detrital plains, abutting on the north against heavy kame-moraines. These hold numerous kettles, and they were certainly built at the stagnant ice margin by glacial outwash into relatively quiet water. The preglacial divides at these passes are probably buried beneath the detrital plains, and may lie some distance south of the present line of water parting.

The characters of these passes and the valleys leading south indicate a flow of water more copious than would be supplied by the melting of merely the local ice margin, and they give a strong suggestion of outflow from the melting ice sheet over Canada and the Adirondacks even greater than by the Springfield channels (see page 79).

NORTHERN TRIBUTARY VALLEYS

Valleys Eastward

Passing eastward from the Susquehanna northern tributary valleys are Cherry Creek, Schenevus, Charlotte, and some small streams on the south. They have been partially described in the preceding pages and the topographic sheets have been named which map the lower portions of the valleys. The Richmondville and Hobart sheets complete the territory.

These valleys all carried glacial waters with heavy detritus. The floods were graded to the high waters in the main valley as base-level, in consequence of which these tributary valleys hold their plains at higher elevations. To map the plains and determine their elevations and gradients, with their relation to the waters in the main valley would be excellent work for the geography classes in the high schools.

Unadilla Valley

Unadilla, New Berlin, Sangerfield, Winfield sheets

In size, form and stream phenomena the Unadilla valley is equal to the Susquehanna above the junction of the valleys at Sidney. The writer has not examined the valley, but the topographic sheets are recent and show the features clearly.

During the life of Lake Herkimer the Unadilla valley carried a glacial flood larger than did the Susquehanna above Sidney. The upper plains, above Unadilla Forks, are very extensive. The descriptions of the other large valleys apply in theory to this valley.

Chenango Valley

Morrisville, Sangerfield, Norwich, New Berlin, Oxford, Greene and Binghamton sheets

The massive detrital deposits in the great valleys of the glaciated territory were formerly regarded as wholly the work of enormously flooded rivers, and in the nature of flood plains and "valley train" drift. We now know that for the low valleys, like the Hudson, Connecticut, and many deep valleys of New England, and the St Lawrence valley, the plains are deposits laid in the sea or in sea level waters, representing marine submergence, previous to the land uplift. In higher valleys, like the Susquehanna and its tributaries, the plains are partly, and in some long stretches wholly, the effects of morainal or drift-barrier lakes.

For the Chenango valley the truth was recognized by Professor Brigham many years ago (25). In 1897 he showed that the valley deposits were largely the work of standing water. He also recognized the effect of the lower attitude of the land. Some quotations are pertinent.

> These beds, with the pronounced frontal slopes and lobes, at Bouckville, appear to prove the existence of a water body into which the material was discharged, at least during the later stages of construction. The lake may have been marginal to a shrinking ice tongue merely, or may have been more extended, filling the valley and prolonged southward. (page 24)
>
> . . . Especially, as we have seen, must we lay aside exaggerated notions of floods coursing with great depth and power and strewing materials throughout the valley. (page 27)

An examination of the valley suggests that moraines probably blocked the valley at some points, perhaps at Plasterville, above and below Oxford, at Greene, and possibly at Chenango Forks. The drift obstructions held the waters as lakes long enough for tributary creeks to build high level deltas in the slack waters.

The distance from Binghamton to Bouckville, at the divide, is 69 miles; and the gravel plains rise in that distance from 940 feet to 1160 feet. The differential land uplift between the two points is 135 feet (figure 2). Deducting this from the present rise, 220 feet, leaves 85 feet for the original slope of the waters, or a total gradient of a little more than 1 foot a mile. This small difference in total level was doubtless taken up in the rapids at the localities of drift blockade.

From the heads of the valley (plate 22) a shallow lake appears to have extended south through the Sherburne valley to Plasterville. Between North Norwich (Galena) and Sherburne Four Corners the kame-moraine was leveled by the waters. In the Sangerfield valley a moraine between Poolville and East Hamilton appears to have held a shallow lake from Hubbardville to Sangerfield, as shown in plate 22. In the Norwich district a lake was probably held by drift blockade in the stretch at Oxford; while another lake may have been held above Greene. There may have been a barrier at Chenango Forks of coarse gravel swept in by the glacial Tioughnioga. Below Chenango Forks the waters were probably confluent with the Elmira and Binghamton lakes.

Speaking of the Binghamton district Brigham says:

> That lake waters occupied the valley in whole or in successive sections, for a long time, is clear. The deeper wells all give in general section beds of gravel of limited thickness, a few to 50 feet underlain by almost massive clays from 120 to 165 feet. . . . It is believed that differential northward depression has in any case been an important factor in the history of these accumulations. (pages 29, 30.)

For fuller description of the Chenango valley the reader should consult Professor Brigham's paper (25), which is accompanied with a map of the glacial features.

Otselic Valley

Morrisville, Norwich, Pitcher and Greene sheets

The name of the Otselic valley is less familiar because the valley is not followed by any line of railway and does not hold any large villages. It is a capacious valley, however, similar to those already described, and it carried heavy glacial drainage. It heads in several branches in the high ground of northwest Chenango and southwest Madison counties, and makes junction with the Tioughnioga at Whitney Point, below which point the combined stream carries the latter name. In preglacial time, however, the Otselic was the main stream, the Tioughnioga having been developed by glacial flow.

Very handsome terraced plains lie at the junction of the two streams, above Whitney Point, also above Upper Lisle. Standing water probably reached to Cincinnatus. The glacial features of the valley are similar to those of the other south-leading valleys of the region. The geography pupils in the Whitney Point High School might study and map the plains between that village and Lisle, and then compare the two valleys northward, and explain the difference in size and character.

Tioughnioga Valley

Cortland, Harford, Greene and Binghamton sheets

The Tioughnioga valley is the best example of forced glacial drainage, with production of new channels, in central New York. The valley heads at Cortland and ends at Chenango Forks. It was developed by tying two small valleys which happened to lie in course with the lower stretch of the Otselic valley. The rock gorge 6 miles southeast of Cortland locates the preglacial divide between the heads of the now connected valleys.

The 4 miles of the present valley above the junction with the Chenango at Chenango Forks is another postglacial channel. The former course of the Otselic is evidently the partly filled valley leading southeast from Itaska (Barker), and which meets the Chenango valley 2 miles above Chenango Forks. Plate 5 shows the preglacial stream relations.

The Chenango valley was so effectively blocked by drift at the Forks that the combined flow of the present rivers has been driven against the west wall of the old Chenango valley, very unlike the normal position of the Chenango and Susquehanna junction in Binghamton.

No slack water deposits are found in the Tioughnioga valley above Lisle, as it was occupied by a vigorous stream.

In the east-leading valley which joins the Tioughnioga at Lisle are some very interesting glacial features. From East Richford to Center Lisle, a distance of 5 miles, the valley is occupied for most of the distance by a large esker, which carried the highway some 3 miles. The subglacial stream which made the esker debouched into a lake at Center Lisle, the plains of which are conspicuous between Center Lisle and Manningville. The geography students here might measure the heights of the lake terraces, and find the controlling outlets of the lake.

Cohocton Valley

Wayland, Naples, Bath, Hammondsport and Corning sheets, plates 23 and 24

This large and important valley is perhaps the finest in the State as an exhibit of glacial river drift, or "valley-train." Fortunately it is not only mapped, but is followed its entire length by two trunk-line railroads, the Erie and Lackawanna, so that it is easily available for car-window observation. Extensive high-level terraces and benches are constant features, on which are located the villages, Painted Post, Campbell, Savona, Bath, Kanona, Avoca, Wallace and Cohocton.

As indicated in plates 4 and 5 the valley was probably produced by uniting several tributaries of the primitive southwest-leading valleys, and the forced union of two such subsequent streams by the glacial flow. It appears certain that the present size and directness from Cohocton down is due to the glacial flood which it carried, during both the advance and recession of the ice sheet. Plate 5 shows the supposed relation of the preglacial drainage.

The Elmira lake reached up the Chemung valley to Painted Post (plate 23), where the Cohocton and Canisteo rivers unite. Above here the wide plains appear to be the high flood plains of the aggraded glacial river. The profile (figure 10) shows the uniform but steep gradient of the plains. Only a minor part of the present slope is due to land uplift, leaving a high gradient for the glacial river.

Many local features should be closely studied; for example, the high gravel deposits and strong lateral channels on the west side of the valley at Cohocton.

Canisteo Valley

Corning, Bath and Hornell sheets, plate 25

Not all of this particularly interesting valley is surveyed. The lower 10 miles, above its junction with the Cohocton, appears on the Corning sheet. The constricted portion, which in preglacial time was probably a drainage divide, is partly shown on the Bath sheet; and the most interesting portion of the valley, from Adrian past Hornell to the head of the valley near Canaseraga, appears on the Hornell sheet.

In origin and direction this valley is similar to the Cohocton; but in form it is unlike the latter. A long stretch of narrow valley from Canisteo down to Addison, a distance of about 25 miles, must have been in preglacial time the paths of two small divergent streams, as indicated in plate 5. In glacial time the valley carried for a long episode the overflow of the Genesee river drainage area (32, plates 11 and 12), which is responsible for the present deep channel. The wide stretch from Canisteo northward, past Hornell and Arkport, was before the ice age the head portion of the broad Dansville valley, and a branch of the Genesee.

The wide portion of the valley holds a variety of unusually good glacial features, which deserve close study and detailed description. The ice tongue which was the last occupant of the valley was the cause of stream erosion along the valley sides, giving horizontal lines, and of local pondings. One of the ice-border lakes has left a delta at the Burden school, 4 miles north of Hornell, the summit outlet being behind the high hill on the South. Other high terraces appear above Arkport and west of Burns. The upper Canaseraga Valley was blocked by the ice lobe, producing handsome lake features in the district of Canaseraga village, which should have special study. A remarkable pitted plain lies east of the village on the brink of "Poags Hole," the creek gorge; and here is the great delta of the Canaseraga creek built in the Dansville lake. These features are partly on the Canaseraga sheet. The wasteweir of the Genesee glacial outflow was the present wide, flat col more than a mile north of Burns, where the effects of river flow over a gravel bottom are clearly shown.

SOUTHERN TRIBUTARY VALLEYS

The small streams tributary to the river from the south and lying east of Waverly have been mentioned. The heavier southern drainage is west of Waverly. The largest stream is the Tioga river, which meets the Cohocton at Painted Post to form the Chemung river. The Tioga, with its western branch, the Cowanesque, drains a large area in Pennsylvania. Other smaller streams flowing directly north are the Seely creek, joining the river south of Elmira, and the Bentley creek, coming in at Wellsburg.

The difference in the glacial history between the north and the south tributaries has been described, page 69.

We have few topographic maps of the Pennsylvania area, and no study has been made of these southern tributaries. Judging from the state map the higher waters in the Tioga system might have been forced by the ice sheet into Pine creek and have helped to swell the flood in the West branch of the river. The lower lakes of the Tioga, like the waters of Seely and Bentley creeks may have passed into Sugar creek, to join the north branch near Towanda.

SUMMARY

Told in the current terminology of stream evolution, the physiographic history of the Susquehanna river is a tragic story. The old river has experienced many vicissitudes. It has suffered the fateful effects of rock control and of robbery by rival streams. It was beheaded, dissected and diverted by pirate streams, and in Tertiary time was partly reversed in its direction of flow. In later time it was blocked, reversed and finally entirely extinguished in New York by the resistless continental Quebec glacier. The final withdrawal of the ice sheet has permitted the renewal of the river, but with altered and subdued character.

This dramatic history, covering tens of millions of years, involves complex geologic factors: the erosion and lowering of the land surface, the diverting effect on the primitive (consequent) drainage by the varying character of the rock strata, changes in the altitude and slope of the land, climatic variations, and the revolutionary effect of glaciation. It is not possible to apportion the relative influence of the several factors, nor to discern the details in the long process of the evolution of the present Susquehanna river system. Nevertheless, a few of the culminating phases are recorded in the existing topography and the geologic deposits, and a brief epitome of the long history is here attempted.

The primitive Susquehanna, with neighboring streams of central New York, came into existence when the area was irregularly lifted out of the interior (epicontinental) sea. This occurred in later Devonian and early Mississippian (Subcarboniferous) time. When the river had its birth, and during its earlier life, there was no Mohawk valley or Ontario basin, as these depressions were subsequently carved out of the Devonian and subjacent strata. The early rivers had their sources in the Adirondack area, or even farther north in Canada, and flowed southwestward into the receding sea, or interior gulf of the ocean, which then lay over Pennsylvania. The extended course in Pennsylvania of what is now the headwaters stretch in New York was in the line of the present Tunkhannock valley, which is crossed at Nicholson by the great new viaduct of the Lackawanna railroad (plate 27). That course is shown in the map, plate 4.

During the immensely long eras of the Mesozoic and Cenozoic (Tertiary) the Mohawk valley and the wide Ontario valley were excavated in the thick and weak Ordovician and Silurian shales. The upper courses of the primitive Susquehanna and its companions, in the Adirondack region, were cut off or "captured" by the creation of the new "subsequent" Mohawk valley and its producing streams.

In manner similar to the diversion of the Adirondack portion of the river, the New York stretch of the beheaded river was diverted westward by the development of west-flowing "subsequent" tributaries in the Chemung shales along the south border of the State, producing the valley from Lanesboro to Waverly. We apply the name Susquehanna to the diverting or capturing "pirate" stream: the beheaded Susquehanna being the present Tunkhannock creek.

By the union of east and west tributaries of the original south-flowing streams in northwest New York a great master stream was developed along the axis of the Ontario basin, which we may call the Ontarian river. That great river probably had westward flow into the oceanic waters in the Mississippi embayment. With the great depth and width of its valley it drew to itself, on the south valley wall, the drainage of western New York, and caused the reversed (obsequent) north-flowing streams of the Finger lakes valleys, and of the Genesee river. It is almost certain that the Ontarian river also reached out through the Seneca valley and captured the Susquehanna. Then the drainage of all central and western New York flowed north and passed out by the Ontarian river to the Mississippi. The Tunkhannock and its companions on the west, Meshoppen and Wyalusing creeks, and the Lackawanna on the east, were the only representatives of the original southward flow. This phase of the preglacial drainage is shown in plate 5.

That adjusted and mature drainage of later Tertiary time was doomed to entire obliteration. With the creation of an ice field in eastern Canada, and its extension and southward invasion as the Quebec glacier, the Ontario valley became filled with the ice body, and the Ontarian river was extinguished. Its north-flowing tributaries were dammed and also finally extinguished, and all the territory of the north branch of the Susquehanna, except a few miles below Berwick, was buried beneath the ice sheet for scores of thousands of years.

Eventually the climatic factors which had produced the slightly lower world temperature of the Glacial period reacted, and when the temperature had risen to a point where the ice sheet melted faster than it was fed by snow fall, the south margin of the glacier slowly receded and released the land surface. The river grew headward, following the retreating ice front. But the south flow had so deepened the channel at and south of Towanda that the river has retained its southward course.

It appears that the glaciated territory was depressed by the weight of the ice sheet, and when the ice was removed, this area stood below its present, upraised level (figures 1 and 2). The reduced gradient of the rivers assisted by the many drift blockades produced lakes and sluggish waters in many districts. The largest of the Susquehanna lakes were the Wilkes-Barre-Scranton lake in Pennsylvania, and the two lakes in the Binghamton and Elmira districts. Into these waters and the smaller lakes in the upper valley, and in the lower gradient tributaries, the glacial outwash and the land drainage swept a great volume of detritus, left as wide plains of gravel and sand. When the barriers in the lower valley were removed, the lakes were drained and the streams were revived by the tilting rise of the land. The erosion of the plains, whether lake or river deposit, by the rejuvenated drainage has produced the conspicuous benches and terraces along the valley sides.

The valleys of western New York lie in four directions and represent four successive stages in the evolution of the drainage (1) the valleys with southwest trend are the oldest, and are probably inheritances from the early Paleozoic rivers (plate 4); (2) the valleys with east and west direction, as the Mohawk, Ontario and one stretch of the Susquehanna, are of later origin, being subsequent valleys developed by rock control and diverted flow; (3) the north-leading valleys, the Genesee and those of the Finger Lakes district, are of yet later creation, due to the reversed or obsequent flow into the Ontario basin (plate 5); (4) the southeast-leading valleys are the youngest and owe their development to the flow impelled by the ice sheet (plate 6).

It is not possible to correlate closely the stages in the history of the Susquehanna with geologic time periods, but a general reference may be ventured. The primitive southward, or southwestward, flow was established when the area was rising for the last time out of the receding sea, in later Devonian time, and it was extended into Pennsylvania during Pennsylvanian (Carboniferous) time. The date of the beheading by the Mohawk valley is uncertain, perhaps early or middle Tertiary. The capture and westward diversion along the south line of the State was probably later, and may be synchronous with the northward turn through the Seneca valley, which was completed in the latest Tertiary. The southward flow through

Pennsylvania was compelled by the advancing Quebec glacier and confirmed during the removal of the glacier. Whether the river ever had the southward course in Tertiary time is a question.

Doubtless all the large valleys except the first and fourth classes owe their dimensions and form to the erosion in the later Tertiary, even if some of them were outlined during the long peneplanation of the Mesozoic. Drainage in some form and direction covered the territory during the Mesozoic era, and the earliest uplift of the Tertiary probably revived the rivers in their former channels.

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Plate 26

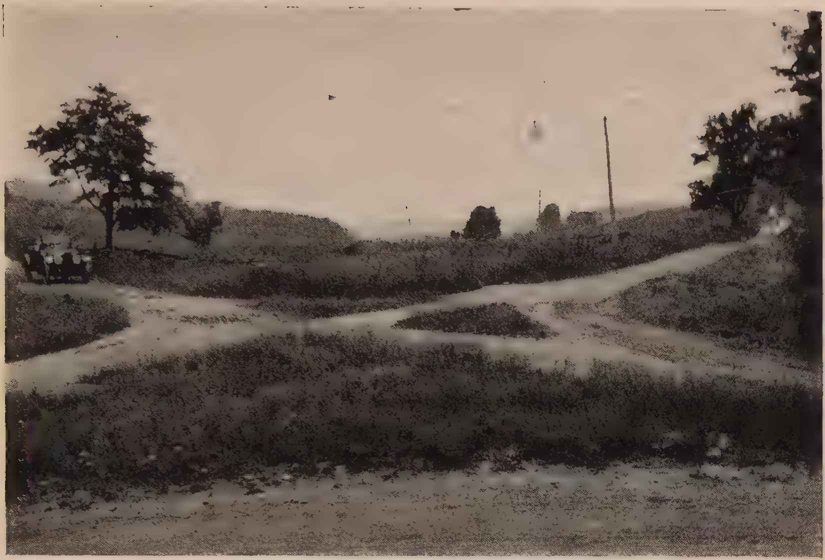

Fig. 1 Rosskelly Corners, 5 miles south of Susquehanna village. Head of the Tunkhannock valley. Looking south.

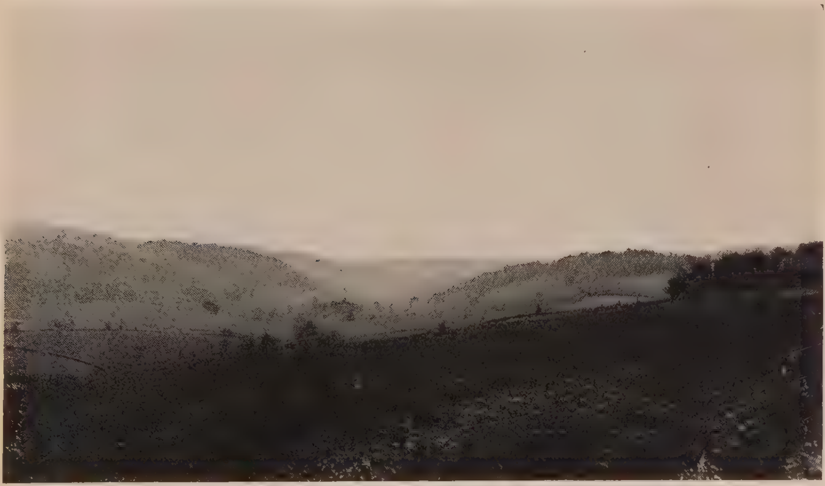

Fig. 2 View looking south down the Tunkhannock valley from point one-fourth mile below Rosskelly Corners.

HEAD OF TUNKHANNOCK VALLEY, THE PATH OF THE PRIMITIVE SUSQUEHANNA

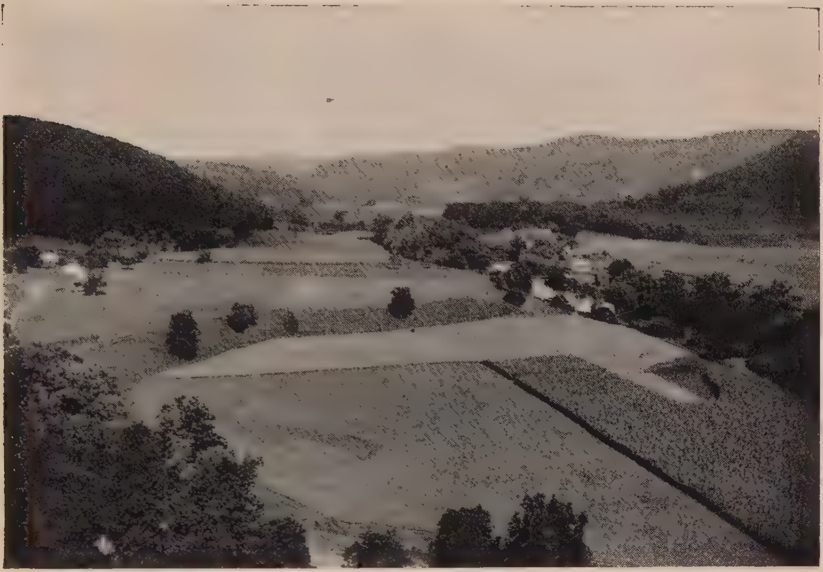

Fig. 1 Tunkhannock valley at Nicholson, Pa., looking east, upstream.

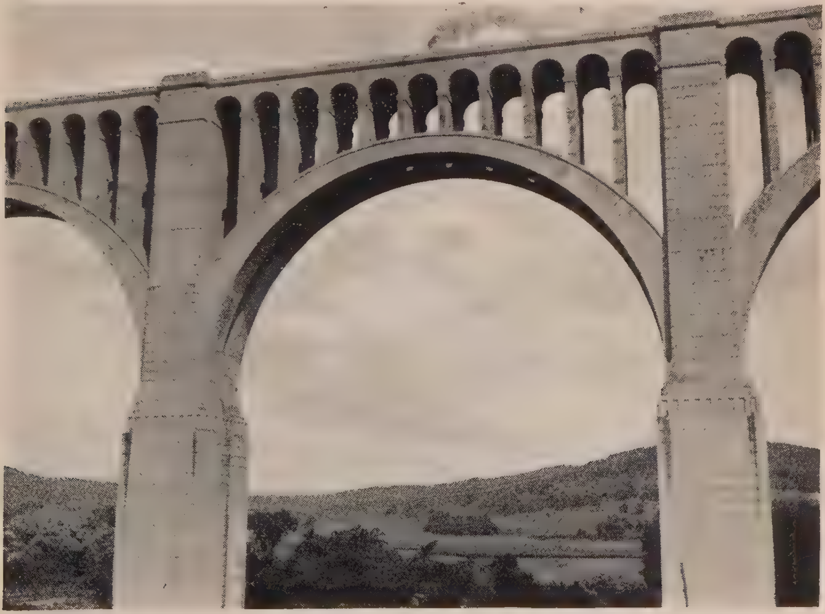

Fig. 2 Viaduct of the Delaware, Lackawanna and Western R. R. across the Tunkhannock valley at Nicholson, Pa.

TUNKHANNOCK VALLEY AT NICHOLSON, PA.

Plate 28

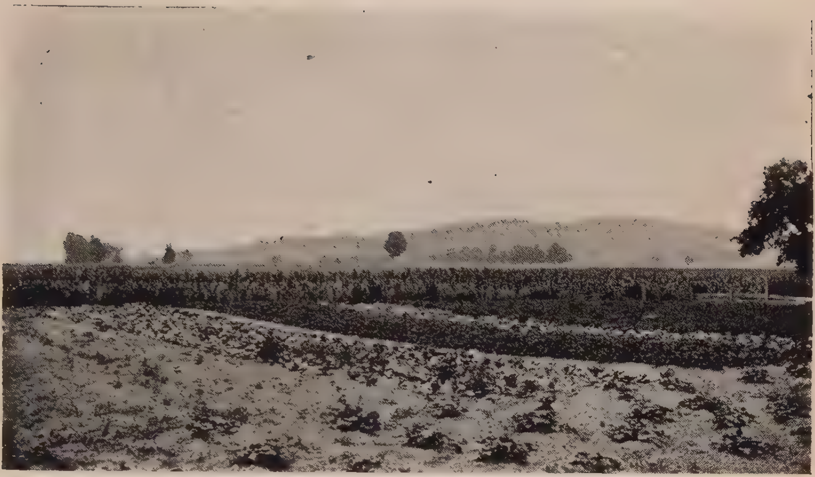

Fig. 1 Delta gravel plain, 2 miles northeast of Horseheads. Looking north. Altitude 940 feet.

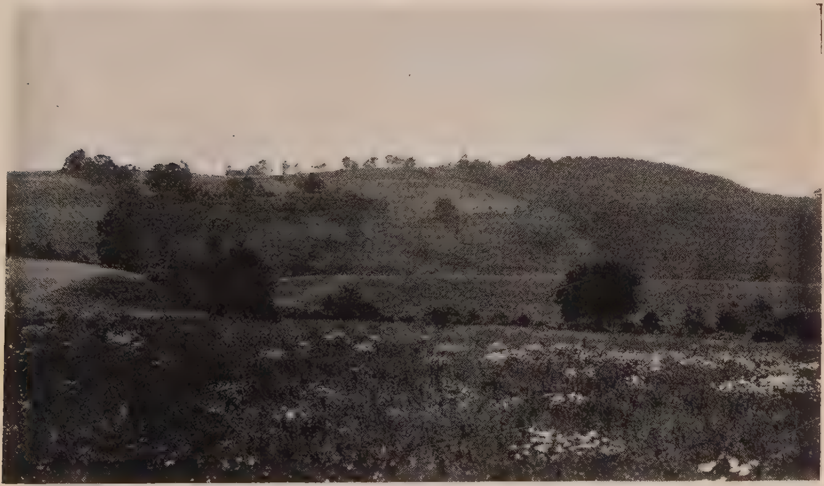

Fig. 2 Terrace southwest of Pine valley. Looking west. Altitude 960 feet.

DETRITAL PLAINS OF LAKE ELMIRA

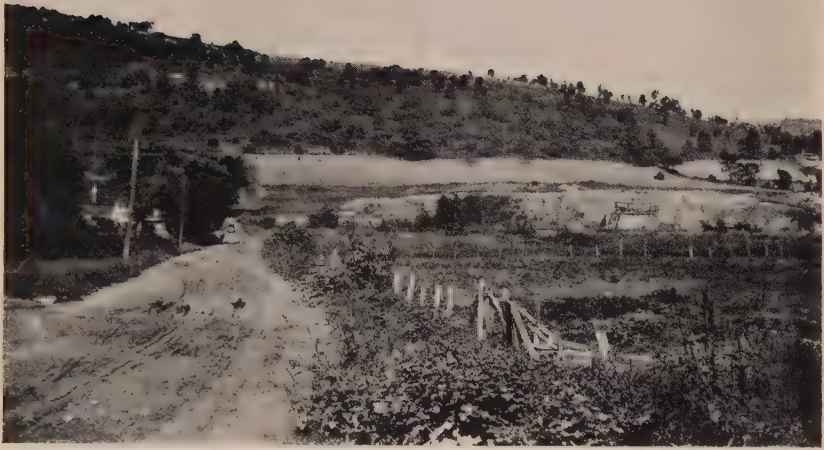

Fig. 1 Remnant of terrace east side of Newtown creek, Elmira. Looking east from bridge over creek at Linden place.

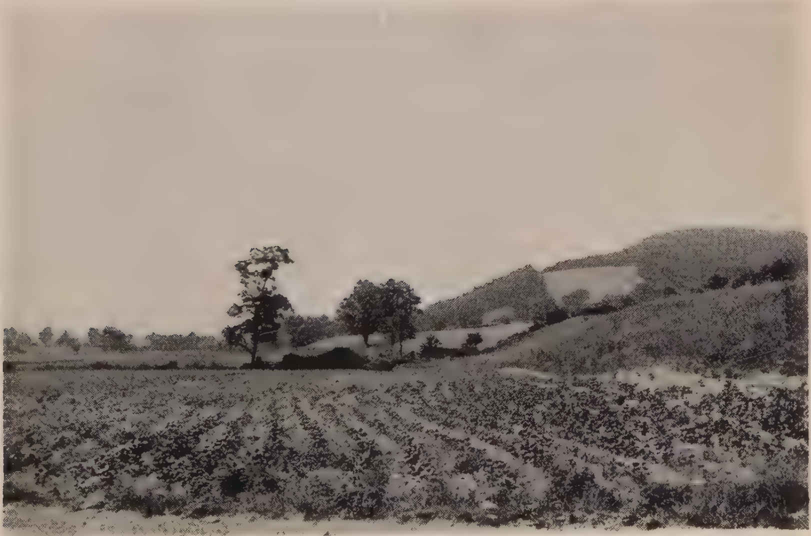

Fig. 2 East bank of Lake Newbury outlet, 2 miles south of Horseheads, by Latta brook road. Looking north. Altitude 890 feet.

FEATURES AT ELMIRA

Plate 30

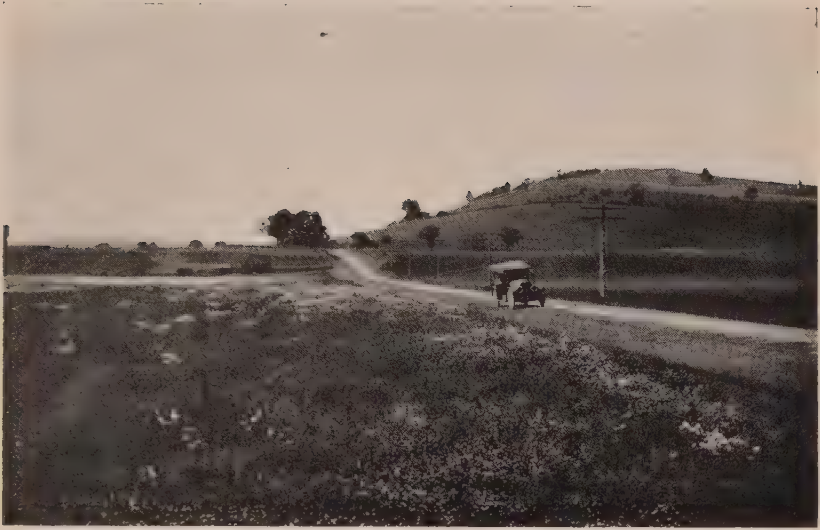

Fig. 1 Terraces at Flemingville, N. Y., at junction of west and east branches of Owego creek. Looking north.

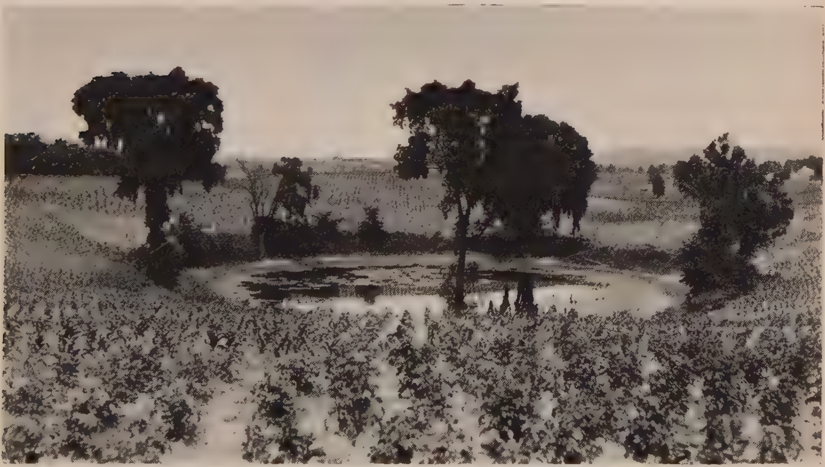

Fig. 2 Ice-block kettle in old flood plain of the Susquehanna river, 3 miles southwest of Owego. Looking north from highway.

Features Near Owego

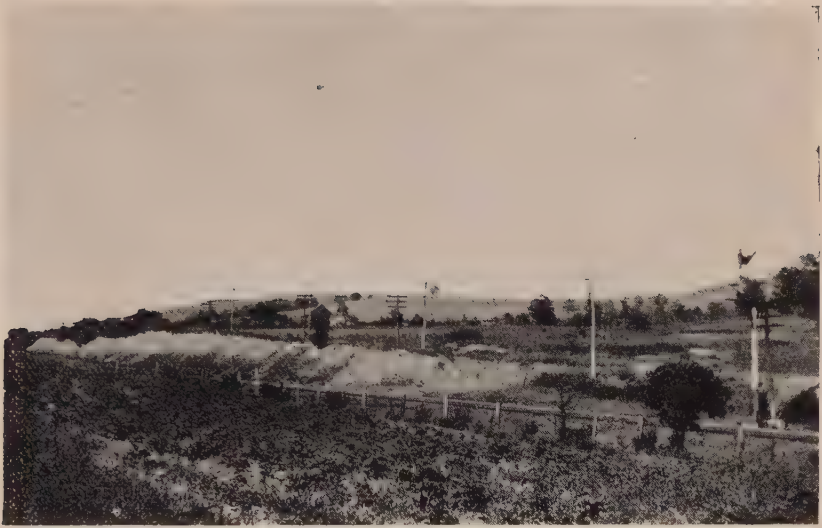

Fig. 1 Cut in delta plain by the Delaware and Hudson R. R., north edge of Binghamton. Looking northeast. Elevation 930 feet.

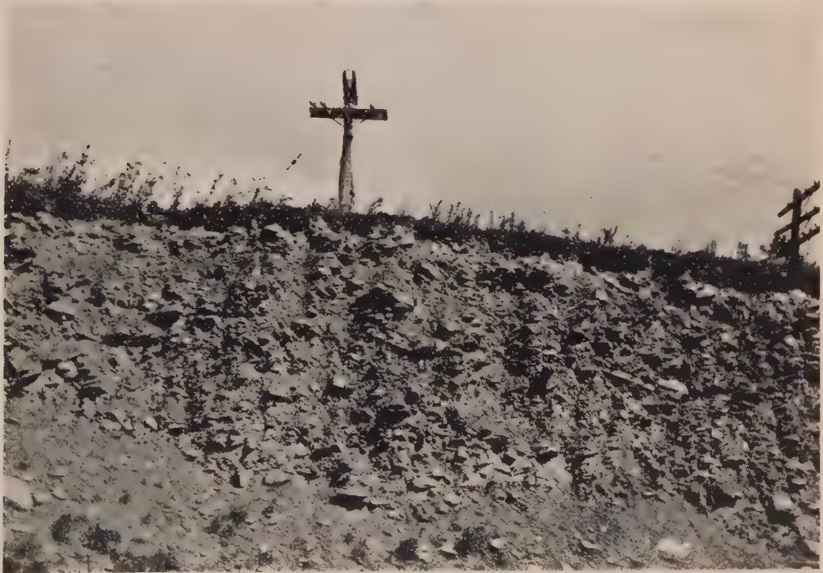

Fig. 2 Close-up view at north end of cut in fig. 1, showing deposit by the torrential stream.

Delta in Binghamton Lake

Plate 32

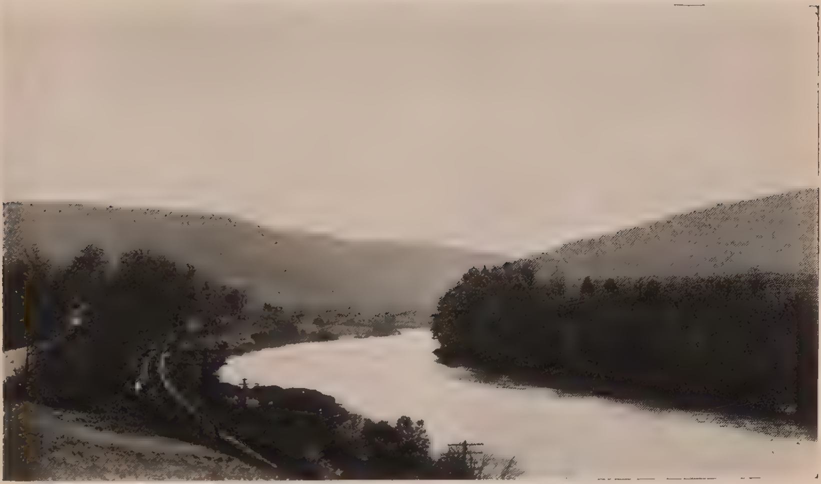

Fig. 1 View looking upstream. Rock cliff at right.

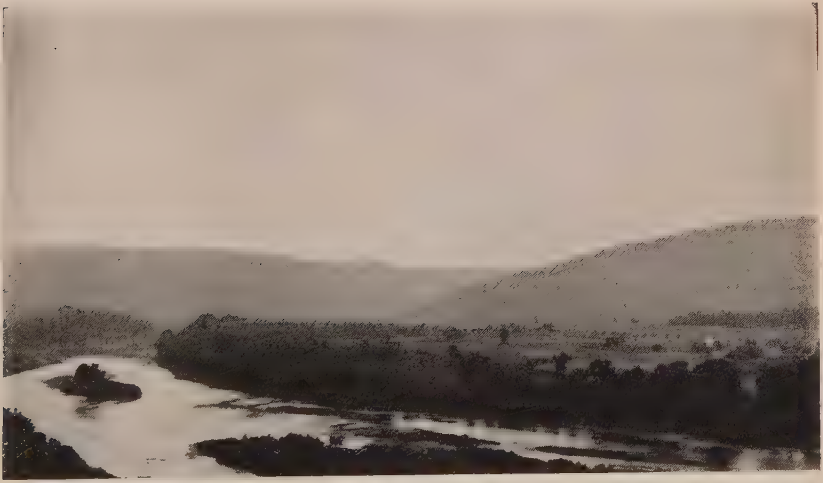

Fig. 2 View looking upstream, Red Rock ravine in the distance.

Red Rock Ravine, Susquehanna River, Two Miles Above Great Bend, Pa.

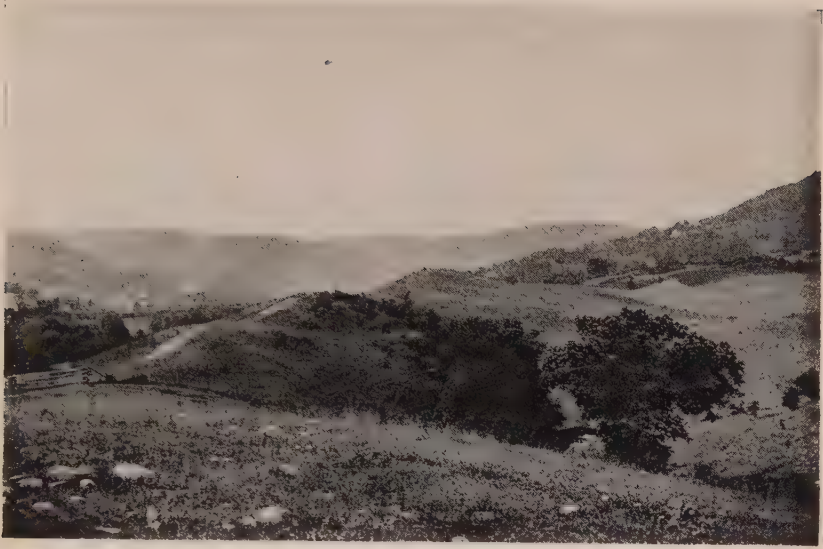

Fig. 1 View looking southwest. River in valley at left.

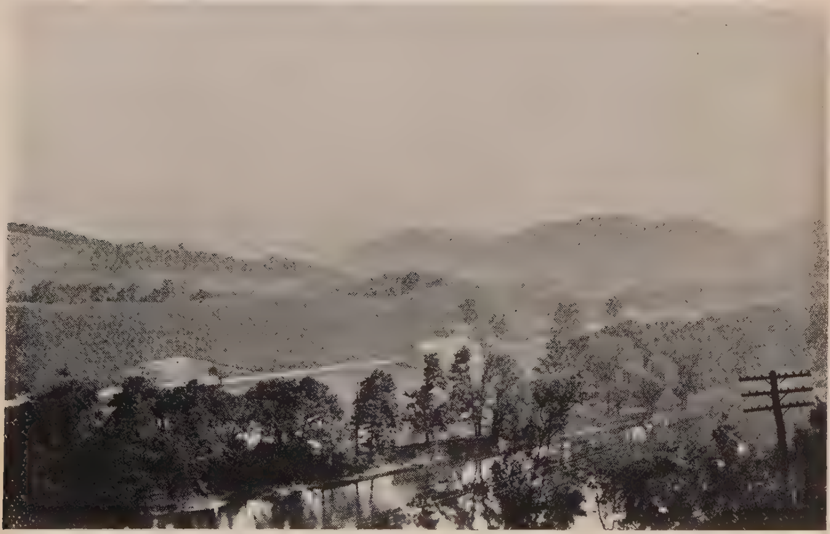

Fig. 2 View looking northeast, across the river, from eastern edge of Susquehanna village.

ESKER IN VALLEY OF THE SUSQUEHANNA AT LANESBORO, PA.

Plate 34

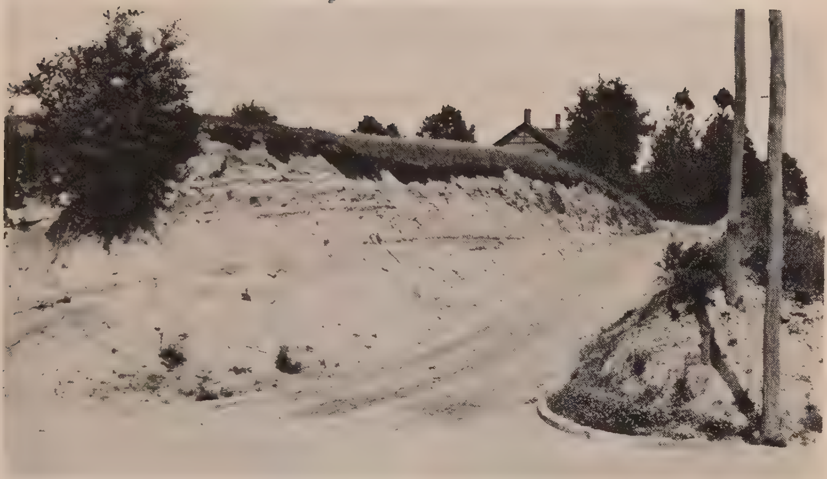

Fig. 1 Highlevel sand beds, South Main and Secor streets, Sidney.

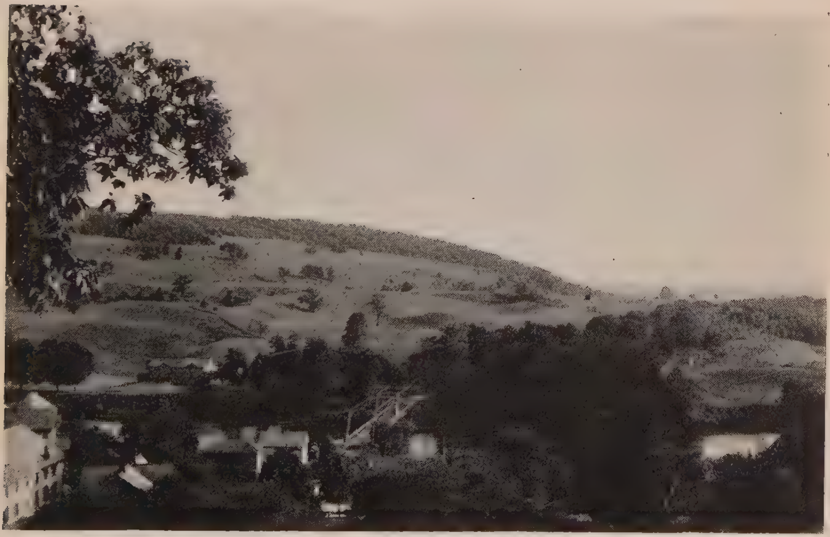

Fig. 2 Terraces at Wells Bridge. Looking southwest, across the river. Summit terrace 1150 feet.

TERRACES AT SIDNEY AND WELLS BRIDGE

Plate 35

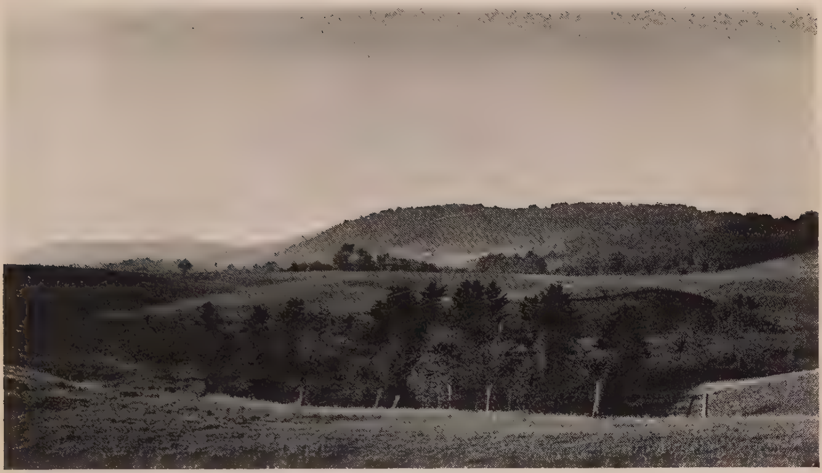

Fig. 1 West of highway. Large basin, looking northwest.

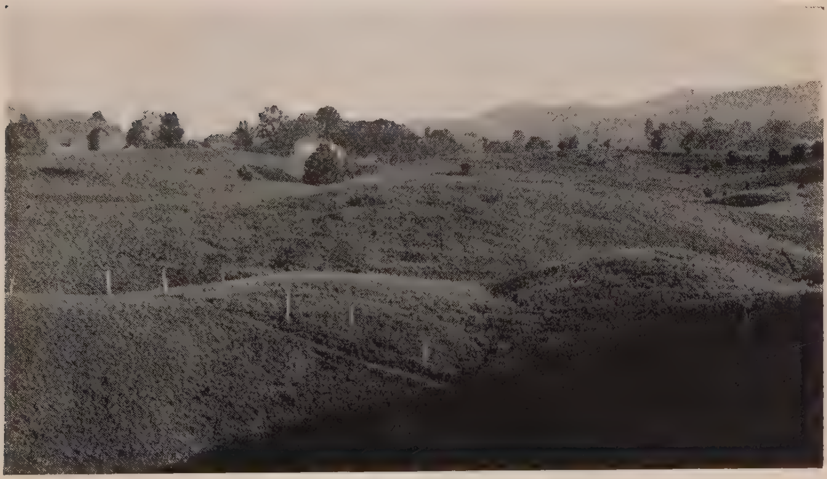

Fig. 2 West of highway. Looking south. Very deep basins in foreground.

Kettles in Plain at Index, Three Miles Southwest of Cooperstown

Plate 36

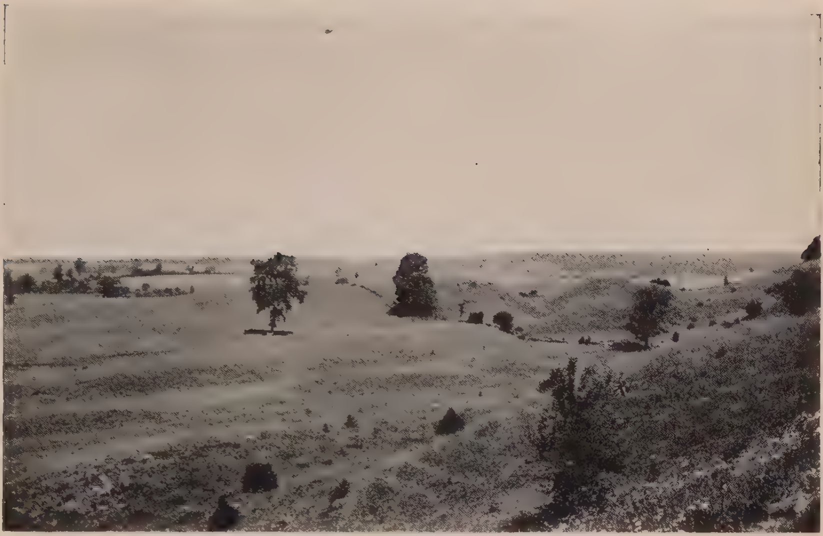

Fig. 1 View looking northwest, from highway, one-half mile east of East Springfield.

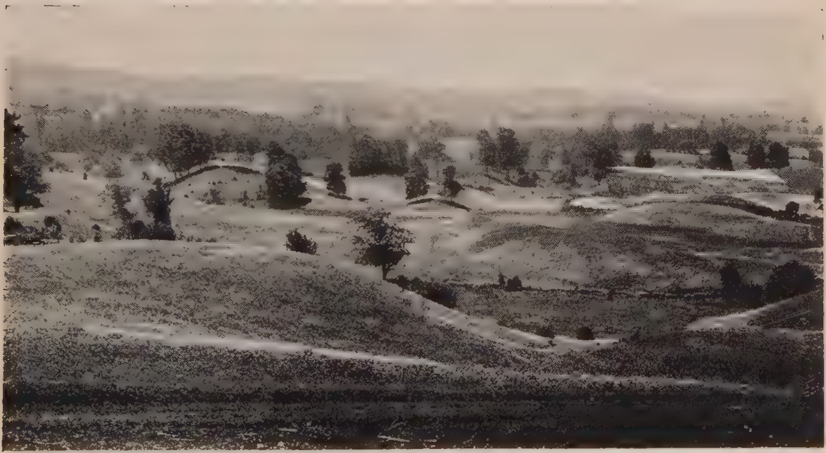

Fig. 2 Looking south from rock knoll one-third mile north of highway.

MORAINE AT EAST SPRINGFIELD

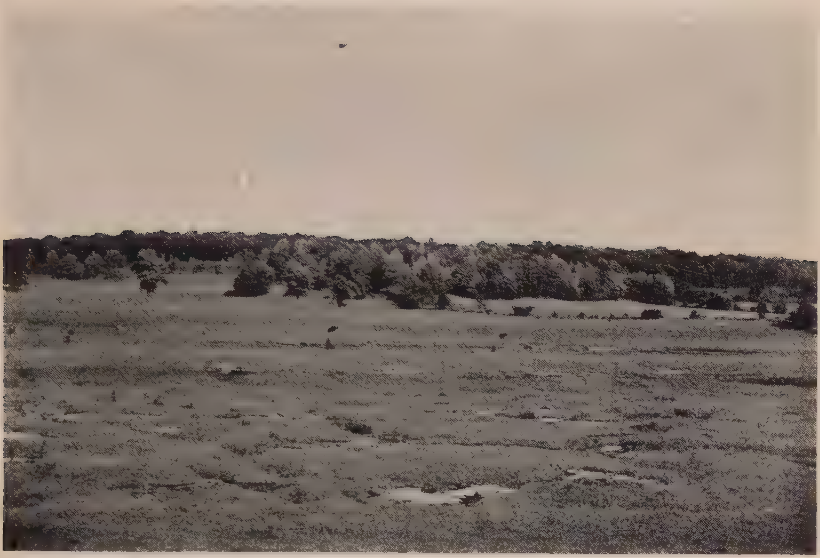

Fig. 1 One mile northeast of East Springfield. Looking east. East bank of glacial river in the background.

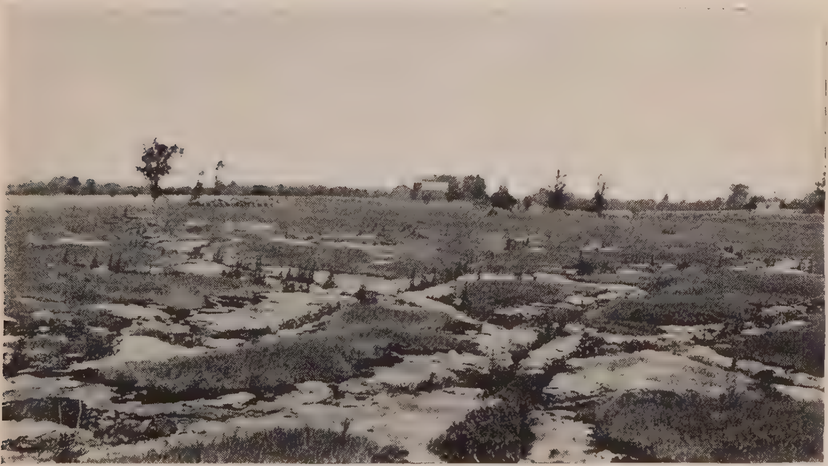

Fig. 2 Floor of glacial river, same locality as Fig. 1. Solution structure in Onondaga limestone.

Channel of Glacial River North of East Springfield

Plate 38

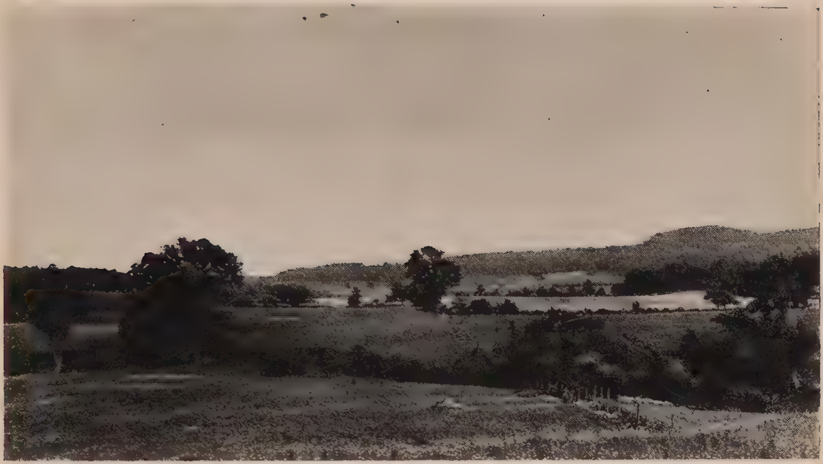

Fig. 1 Plain and terrace, 2½ miles east of north of East Springfield. Looking east from forks of road.

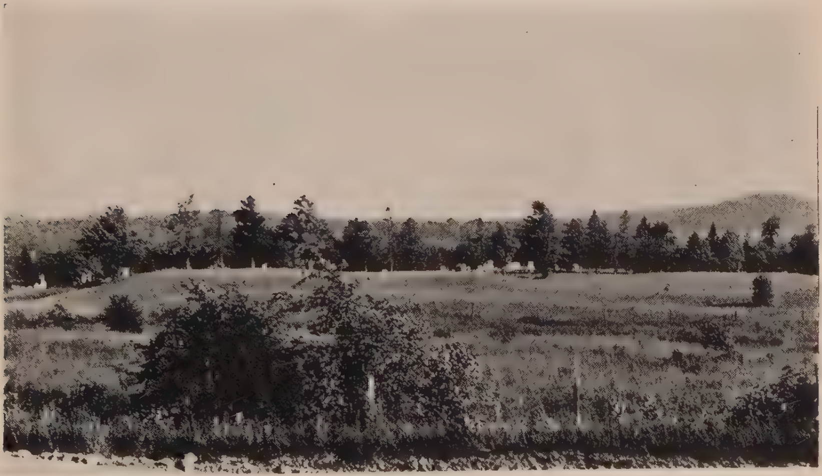

Fig. 2 Delta at Springfield Center, with cemetery. Looking southeast.

GLACIAL DRAINAGE FEATURES NORTH OF OTSEGO LAKE

Plate 39

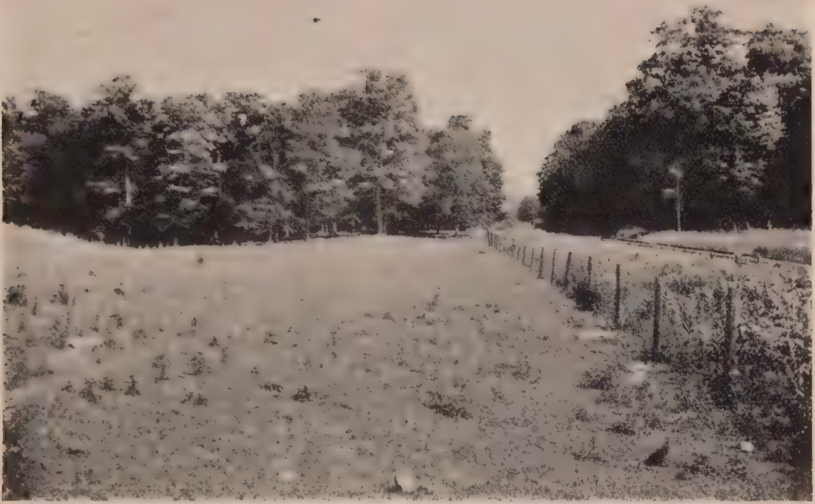

Fig. 1 Divide, and head of channel, 1½ miles northeast of Cherry Valley. Looking north.

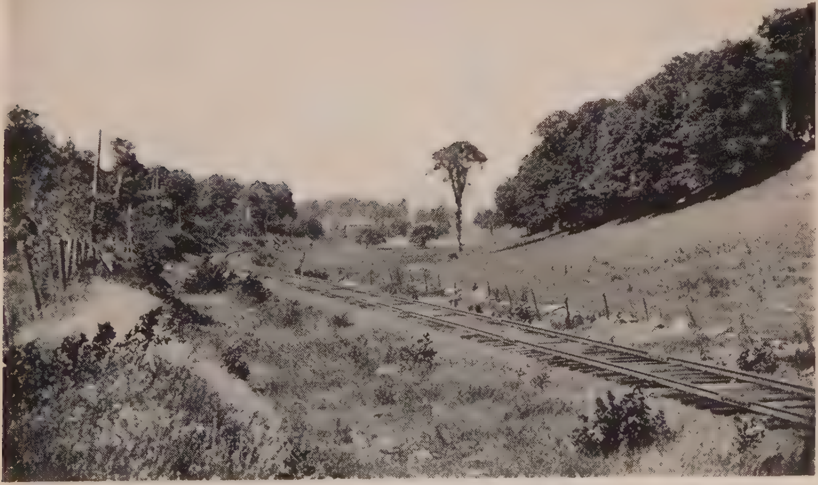

Fig. 2 One-fourth mile south of Fig. 1. Looking south, downstream.

GLACIAL RIVER CHANNEL AT CHERRY VALLEY

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